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FORT EUSTIS, VIRGINIA

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VTOL DOWNWASH IMPINGEMENT STUDY
DUCT ADAPTER TEST PROGRAM

Project 9R38-01-017-29

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prepared by :

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Palo Alto, California

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DUCT ADAPTER TEST PROGRAM

Hiller Engineering Report No. 60-88

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FOREWORD

Hiller Aircraft Corporation was awarded Contract DA 44-177-TC-655 in April 1960 to extend the work performed under Contract DA 44-177-TC-500. This work was to include studies, tests and evaluation of the effects of downwash and slipstream forces of Vertical Take-off and Landing (VTOL) aircraft with respect to aircraft, supporting equipment, personnel and landing areas.

A portion of the work covered by this contract has been fulfilled. Results of surface erosion tests utilizing the downwash from a two-foot-diameter ducted fan were presented in TREC Technical Report 60-67.

This report presents the results of tests conducted at the U. S. Army Engineers Waterways Experiment Station at Vicksburg, Mississippi in September 1960. For these tests the two-foot-diameter ducted fan was fitted with a diffuser. Adapters were used at the diffuser exit to simulate side by side flow for VTOL type machines and annular nozzle and plenum chamber type ground effect machines (G.E.M.). In addition to the test sites and general support of the test program, the Waterways Experiment Station provided the wave rods and recorder equipment used in the water tests and the classification and condition of the materials at the time of testing.

Work remaining to be done under this contract consists of the preparation of a summary report and an edited film analyzing the results of this contract and Contract DA 44-177-TC-500, and presenting recommendations relative to VTOL aircraft design and operation based on conclusions drawn from the analysis.

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LIST OF SYMBOLS

a	Wave amplitude	feet
a_1, a_2 and a_3	Particle trap location with respect to G.E.M. nozzle (see Figures 41 and 42)	feet
a'	Distance between total pressure profile plane and G.E.M. nozzle	inches
D	Duct exit diameter	feet
D_H	Diameter of the eroded section which could be attributed to a single air jet	feet
f	Wave frequency	c.p.s.
h	Height of a point under investigation above normal surface	feet*
P	Local pressure	pounds per square foot
P_T	Total pressure **	pounds per square foot
R	Duct exit radius	feet
r	Radial distance	inches
T	Total thrust	pounds
t	Test time	seconds
V	Velocity	miles per hour
w	Disk loading	pounds per square foot
x	Radial distance from a duct centerline	feet
y	Distance measured from the configuration centerline	feet
Z	Exit height above the surface prior to start of erosion	feet
θ	Thrust axis inclination angle	degrees
ϕ	Azimuth angle measured clockwise (on the ground plane) from principal geometric axis	degrees

* Dimensions in feet unless otherwise noted
** Total gage pressure

NOMENCLATURE USED FOR SOIL CONDITION

		Test Numbers
I	Lean Clay (CL)	
	A. Bladed Section	42 to 45 inclusive
	B. Plowed Section (Flat)	47 to 55 inclusive
II	Fat Clay (CH)	
III	Sand (SP)	
	A. Dry	26 to 41 inclusive 56 to 59 inclusive and 46
IV	Sandy Gravel (GW)	
	A. As Deposited	60 to 68 inclusive
V	Water	
	A. Fresh	1 to 25 inclusive

This system of soil condition nomenclature was used to provide a complete cross reference between this report and Appendix I. A single designation was used which consists of:

1) A Roman numeral that designates the type of soil.
2) An alphabetical symbol that designates the soil preparation.
3) The test number assigned at the time the test was conducted.

A designation can consist of the first two parts when reference is made to a series of tests.

Example: Data designated I-B45.

This data refers to test number 45 which was conducted over a plowed flat surface of lean clay.

Reference to soil condition V A refers to all tests conducted over the fresh water.

1.00 SUMMARY

A mobile test rig, which provided a cold air source with an opening of one-foot full radius ends connected by a 17-inch straight section, was used for these tests. The open end of the air supply was used for the plenum chamber G.E.M. configuration. An adapter was provided which incorporated a .6 inch thick annular nozzle inclined at 45 degrees toward the base plate. An additional adapter, with two one-foot-diameter spun aluminum ducts installed with centers two feet apart, was used to investigate the interference caused by twin air jets. The side by side ducts were tested in the disk loading range of 8 to 150 pounds per square foot and at Z/D ratios from .5 to 3. The G.E.M. configurations were tested at Z = .25 feet above the undisturbed surface (this exit height corresponded to an effective Z/D of approximately .1). The plenum chamber disk loadings (based on the plenum base area of 5.96 square feet) were 4.36, 8.4, 9.4 and 31.25 pounds per square foot and the annular nozzle disk loadings (based on the base plate plus nozzle area of 5.2 square feet) were 2.13, 9.64 and 16.6 pounds per square foot.

Initial tests were performed over a non-eroding surface to determine the surface flow characteristics of the three configurations. Soil conditions investigated consisted of plowed flat lean clay, dry sand, sandy gravel and water. The test data obtained included soil classification and condition at the time of test, particle trap contents, film records, notes from observations and oscillograph records of the wave rod traces.

The side by side ducts showed the interference to be restricted to a narrow region neighboring the equipotential line. In this region the maximum velocity is essentially the same as the surrounding flow, but the high velocity flow extends to greater heights above the surface. When operated over eroding surfaces the annular nozzle configuration produced considerable vertical projection of the airborne particles at all disk loadings. The plenum chamber configuration tests were similar to the side by side ducts at the lower disk loadings in that the flow spread along the ground surface. At high disk loadings with the side by side ducts the initial flow spread along the ground, but as the erosion produced cavities the flow was projected above the surface.

2.00 CONCLUSIONS

As this is an interim report, the purpose of which is to present the test data, the conclusions are restricted to those that are drawn directly from the test results and pertain specifically to those tests.

When a pair of jet streams impinge on a surface in proximity to each other, the results are the same as they would have been had the jet streams been free of mutual interference, except for a narrow region neighboring the equipotential line. In this region the maximum velocity is essentially the same as the surrounding flow, but the high velocity flow extends to greater heights above the surface.

The plenum chamber exhibited tendencies to produce the same overall pattern as the side by side ducts. (If the side by side ducts were brought progressively closer together, the configuration of the plenum chamber would be approximated when the centerlines were separated by one radius.)

The identifying characteristic of the annular nozzle tests was the vertical projection of loose material.

The nozzle flow turned approximately 225 degrees. The nozzle was directed under the base plate at 45 degrees and the visible air-borne material was essentially vertically projected.

3.00 INTRODUCTION

The operation of helicopters, vertical lift types of aircraft and ground effect machines from unprepared surfaces presents problems associated with the downwash or slipstream impingement. Among these problems are the effects on: the pilot; the aircraft physically and operationally; tactical operation of the aircraft; and danger to ground personnel and equipment, resulting from dust and debris set in motion by the downwash or slipstream.

In 1958 the U. S. Army Transportation Research Command (USA TRECOM) awarded to Hiller Aircraft Corporation Contract DA 44-177-TC-500 to study the characteristics of the downwash from VTOL aircraft. In the tests of that program the downwash from propellers and a ducted fan was impinged on a flat non-eroding surface, and velocity profiles and flow directions were obtained (TREC Technical Report 60-58).

In April 1960 Contract DA 44-177-TC-655 was awarded Hiller Aircraft Corporation to conduct additional tests and evaluation of the effects of the downwash impingement on a variety of soil conditions. TREC Technical Report 60-67 covers a portion of that work, consisting of test results of a two-foot-diameter ducted fan impinging on various types of surfaces. The results of the remaining portion of the test work accomplished under this contract are presented in this report.

It should be noted that the primary purpose of this report, as it was in TREC Technical Report 60-67, is to present the results of the tests conducted. Only the more obvious conclusions based on the test observations are presented. No attempt to analyze the test results has been made.

To obtain information that would allow even the most general answers to questions concerning problems that might arise on this subject would require an enormous amount of testing. When one considers the variables connected with the air jet generator - for example, jet velocities and shapes, pulsations, impingement angles, heights above the surface, ground winds present - and adds the variables present when considering possible landing areas (such as soil types as to textural and plastic qualities, moisture content, surface irregularities and changes in the surface during impingement of the jet), it becomes immediately apparent that the program covered by this report could only lead, at best, to very general results and possibly point the way for future test work. The reader is cautioned that the results presented in this report were obtained under conditions that allowed only a few of the many above-mentioned variables to be controlled or investigated, and that any attempt to apply these results to specific cases, except in a very general way, is not recommended.

4.00 DESCRIPTION OF TEST EQUIPMENT

4.01 TRUCK TEST RIG (FIGURE 1)

A U. S. Army Model M-54, 5-ton, 6x6 cargo truck with a front-mounted winch was used as a base for the test rig. A parallelogram boom, with main arms 14½ feet long, was mounted to the truck bed. Supported on the arms was a Ford Model 332 industrial V-8 engine, displacement 332 cubic inches, continuous horsepower rating 128 at 2800 rpm. A five-speed, truck-type gearbox was mounted on the engine and provided input to output ratios of 1:1, 1.48:1, 2.40:1, 4.38:1 and 7.58:1. The output shaft from the gearbox was attached to a right angle drive unit with an input to output ratio of 1:2.69. This unit was mounted so the output end could be rotated about the main drive shaft axis. This allowed the thrust axis to be inclined from 0 to 90 degrees in 30 degree increments. The propellers were mounted on the output shaft.

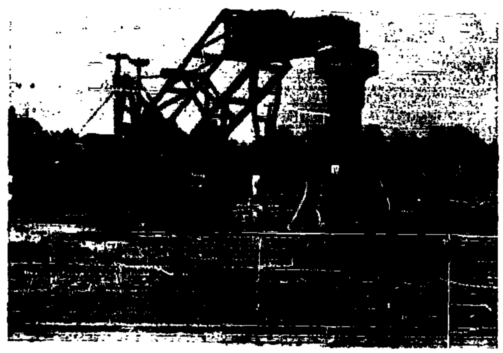


Fig. 1. General Arrangement Test Equipment

The propeller height above the ground was varied by raising and lowering the boom assembly with the winch cable. This height could be varied from six inches to 14.5 feet.

4.02 DUCTED FAN ASSEMBLY (FIGURE 2)

The air generator for these tests was a two-foot-diameter ducted fan. The single rotation propeller contained six three-inch chord, RAF-6 airfoil section blades machined from aluminum alloy forgings mounted in a split hub that allowed the pitch of the blades to be ground adjusted. The blade tip was set at approximately 17.7 degrees for these tests. Mounted to the duct below the propeller was a set of five three-inch chord, molded plastic, straightening vanes designed to remove the swirl from the exit air stream. The three-foot-long

duct was turned from a laminated cylinder of sugar pine. It was mounted to the main support shaft by a welded tubular steel support. The duct shape consisted of a lemniscate inlet followed by a cylinder, with the propeller and straightening vanes located near the exit.

Fig. 2. Ducted Fan Assembly
Two-Foot Diameter

4.03 INLET SCREEN (FIGURE 1)

A duct inlet screen of 1/4-inch mesh was fitted over the duct support tubes to prevent solid particles from falling into the duct inlet. The screen did not completely close the inlet, an annular space between the outside of the duct and the bottom of the screen being left open.

4.04 TACHOMETER (FIGURE 3)

A Hewlett-Packard Model 500C electronic tachometer was used to determine accurately the propeller rpm. The tachometer uses a photo cell to sense intermittent reflected light from the propeller drive shaft.

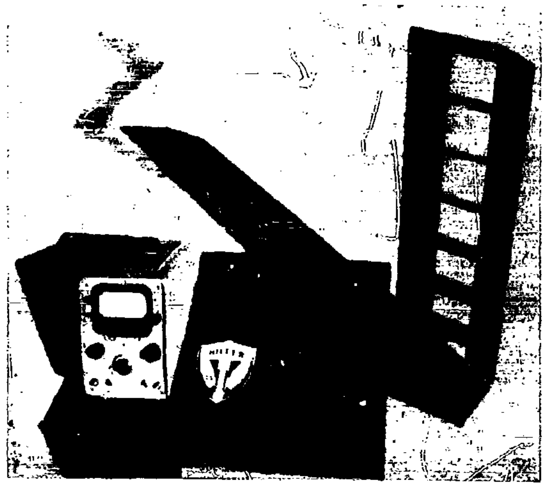


Fig. 3. Instrument Panel, Tachometer and Particle Trap

4.05 INSTRUMENT PANEL (FIGURE 3)

A portable instrument panel containing the controls for the propeller power plant was used. Mounted on the panel were the ignition switch, starter switch, throttle control, camera remote control switch, clutch controls, an engine tachometer and an instrument for measuring barometric pressure.

4.06 PARTICLE TRAPS (FIGURE 3)

Three particle traps constructed of 1/4-inch-thick plywood with a plexiglass back were used. These traps were thirty-two inches tall, six inches wide and six inches deep. They were set in the ground four inches deep leaving twenty-eight inches protruding. The exposed area was divided into seven equal compartments with the bottoms sloped rearward at approximately 30 degrees.

4.07 CAMERAS

A 35 millimeter camera was used for all black and white test photographs of particle movements and eroded sections. A 16 millimeter movie camera was used to photograph some typical test runs.

4.08 WAVE RODS (FIGURE 4)

Six wave rods were supplied by the Waterways Experiment Station. These rods were approximately one foot long, 1/4 inch thick and 1/2 inch wide, and supported two wires separated by insulating material. These rods were mounted to a submerged steel angle structure so that the upper ends protruded approximately three inches above the water. These rods were used as sensing elements in parallel to a portion of a balanced full bridge. An unbalance, caused by changes in the water height, was reflected to the bridge, amplified, and recorded on an oscillograph type recorder.

Fig. 4. Wave Rod Installation

4.09 DUCT DIFFUSER (FIGURE 1)

To accommodate the adapters simulating the side by side flow for VTOL aircraft and the ground effect machines, a diffuser approximately 71 inches long was constructed. Its cross section was a smooth transition from a two-foot-diameter to an oblong shape two feet wide and

17.15 inches long with one foot radius semicircular ends (see Figure 41). The exit area was 5.955 square feet. It was constructed of formed aluminum alloy sheet metal and aluminum alloy extruded stiffeners attached to a circular steel ring inlet. A full width vane 32 inches long was installed on the center of the diffuser along the minor axis. The lower end of the vane could be adjusted to regulate the flow distribution at the exit.

4.10 SIDE BY SIDE FLOW ADAPTER (FIGURE 5)

To simulate the air flow from VTOL aircraft with more than one air source this adapter was utilized. It was constructed of a cover sheet of aluminum alloy with aluminum alloy extruded stiffeners. Two eight-inch-long, one-foot-diameter spun aluminum ducts were riveted in cut-outs in the cover sheet with their center lines two feet apart.

Fig. 5. Side by Side Flow Adapter

4.11 ANNULAR NOZZLE (FIGURE 6)

This adapter was constructed of a welded aluminum alloy ring supporting a wooden center body by means of 12 equally spaced bolts and spacers. The nozzle angle was 45 degrees directed inward and had a width of .60 inches.

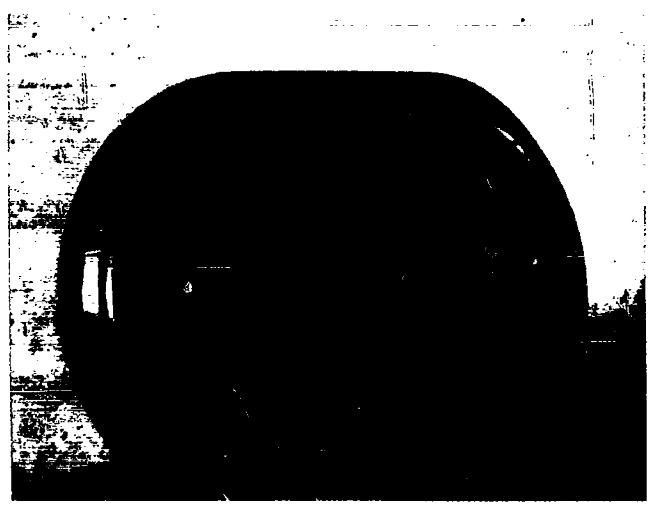


Fig. 6. Annular Nozzle Flow Adapter

4.12 BOOM STRUT (FIGURE 1)

This strut, used for obtaining close control of the propeller height above the test surface, was constructed of 3-inch-deep channel sections with 2-inch steel angle cross members. It was attached to the lower boom arm by means of 3/4-inch-diameter pivot bolts. It was stabilized to the truck bed by means of a 2-inch steel angle brace. Additional strut length was provided by extensions constructed of 3-inch-diameter steel tubing bolted to the base.

4.13 VELOCITY RAKE, DUCT EXIT (FIGURE 5)

Two rakes, of four total tubes each, were constructed of 3/16-inch-diameter copper tubing. The tubes were equally spaced so as to survey the exit total pressure of the two side by side one-foot-diameter ducts. Sheet metal brackets soldered to the tubes held the rake in place at the duct exit.

4.14 TOTAL PRESSURE RAKE, EIGHT TUBE (FIGURE 7)

This rake was constructed of eight 3/16-inch-diameter copper tubes soldered to a sheet metal angle support. This rake was used for obtaining total pressure profiles along the ground plane with the duct adapters.

Fig. 7. Velocity Rake, Eight Tube

4.15 MANOMETER PANEL, TEN TUBE INCLINED (FIGURE 8)

The structure of this panel was plywood on which a welded steel tank was attached. Connected to the tank were ten 1/4-inch-diameter plastic tubes. With the base level as indicated by the side mounted bubble, the slope of these tubes was one in four. An adjustable

reservoir was provided to allow the neutral position of the water to be adjusted. Metal scales graduated in centimeters were attached between the plastic tubes.

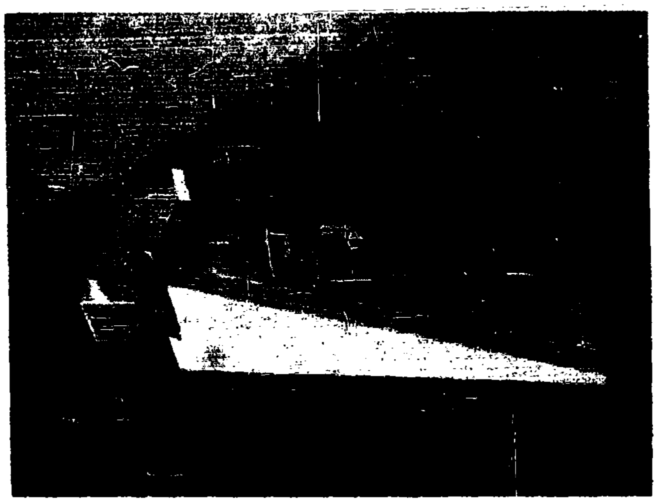


Fig. 8. Manometer Panel, Ten Tube Inclined

5.00 EXPERIMENTAL PROCEDURE

5.01 CALIBRATION

Direct thrust measurements were impractical due to the relative magnitude of the thrust and weight of the test equipment. The thrust reaction on an eight-foot-square ground plane was used for calibration. The ground plane was constructed of 1/4-inch plywood stiffened with 2x4 inch lumber, and supported on two standard platform scales. A screw jack under the boom support strut was used to adjust the clearance between the ground plane and the duct adapter. The plenum chamber and annular nozzle adapters were tested at only one height, Z = .25 feet. The Z measurement was made prior to each test and was therefore the exit height prior to any erosion which may have taken place. A general view of the test equipment during calibration is shown in Figure 9.

Fig. 9. General Arrangement Calibration Equipment

5.02 FORCE AND PRESSURE MEASUREMENTS

The side by side one-foot-diameter duct adapter was installed with the duct exit rakes mounted and connected to the manometer panel. With the side by side ducts operating out of ground effect, the diffuser vane was adjusted until the manometer panel showed equal flow from the two ducts. This vane setting was then used throughout the test program. Thrust calibration runs were made by continuously monitoring engine rpm while adjusting the clearance between the ground plane and adapter. When the desired clearance and rpm were obtained, platform scales were balanced and the readings recorded. The difference between the pre-run reading and the reading taken during operation was obtained for each scale and the results added to obtain total thrust. Thrust versus rpm curves corrected to sea level standard conditions are shown for the side by side ducts (Figure 38) and the ground effect duct adapters (Figure 39).

The procedure used to obtain pressure data was the same as that for the force data until the proper clearance and rpm were obtained. For the pressure data the rpm was maintained constant while the manometer board was read manually.

5.03 OPERATING PROCEDURE

The test areas were prepared as described in Appendix I. Prior to conducting a test the nozzle was positioned over the site at the height to be tested and the particle traps (or wave rods) were positioned about the adapter as shown in Figure 40 for the side by side duct, Figure 41 for the plenum chamber, and Figure 42 for the annular nozzle adapter. The propeller clutch was engaged and the propeller was brought to the desired operating speed, whereupon a stop watch was started. Photographs and observations were made during operation that normally lasted one minute, after which the propeller rpm was reduced and the clutch was disengaged. Particle trap contents were recorded and the eroded section was photographed and measured. Tests conducted over the water site were not timed. Test time was that required to complete the oscillograph records, motion pictures and observations. Typical tests were photographed with a 16 millimeter movie camera using color film.

6.00 DISCUSSION

6.01 GENERAL

The reduction of the data obtained during tests over soils has been performed in the following manner:

Flow Rate - This parameter has been used for plotting the data obtained from the particle traps. To obtain flow rate the product of the volume of material in a given compartment and the material density of the uppermost soil sample was divided by the product of frontal area of the compartment and the test time. The flow rate is the weight (in pounds) of material passing each minute through a square foot area normal to the ground surface. The use of the uppermost soil sample density as the density of the trapped material eliminated the need to weigh the contents of each compartment. The compartment volume was obtained by measuring the height of material in the compartment and converting this measurement to volume through the use of an appropriate multiplier.

These methods were found to produce good results and greatly increased the number of tests possible by their simplicity.

Hole Contour and Erosion Rate - Tests of the side by side ducts produced two overlapping circular eroded areas (Figure 10). After completing each of several tests over the sand, the contour of the eroded hole was obtained for comparative purposes. The depth was measured at the center and every two inches along a radial line which did not intersect the overlapping section of the eroded area. To obtain the erosion rate a numerical integration was performed that provided the volume of a circular area with the measured contour. This represents the erosion rate of a single one-foot-diameter duct.

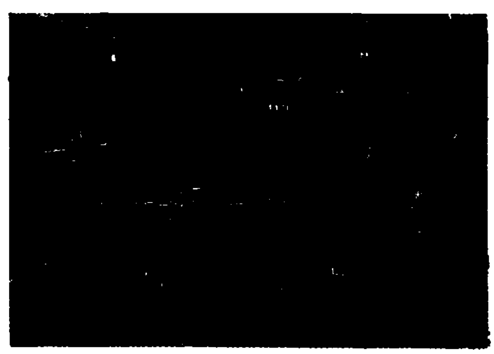


Fig. 10. Test III A 35 After Completion, Z/D = 1.5 w = 150

Hole Diameter Ratio - The hole diameter ratio is based on the diameter of one of the overlapping eroded sections. The diameter of each of the pair of eroded holes was normally the same; however, because of non-uniformity in the soils one was sometimes larger or was larger in one direction. The largest diameter was used to construct the plots

of diameter ratio versus disk loading. The reduction of data for the over water tests consisted of reading data from the oscillograph and plotting the displacement, wave amplitude and frequency for each of the five wave rods.

Pressure Measurements - To provide information for correlation between the different configurations, ground total pressure surveys were made over non-eroding surfaces, using the total pressure rake shown in Figure 7. The total pressure is equal to the dynamic pressure for the measurements taken farthest from the nozzle exits, and the dynamic pressure would be slightly less than the total pressure for the measurements very close to the nozzle exits.

Side by Side Ducts - The side by side, one-foot diameter ducts were operated at a $Z/D = 1.56$ and a disk loading of 44.6 pounds per square foot. The total pressure rake was used to survey the ground flow along the $\phi = 0$, 45, and 90 degree directions from the x origin and along the minor axis of symmetry. The profiles obtained at $\phi = 0$, 45, and 90 degrees are very similar (Figures 43, 44 and 45 respectively) and of the magnitude to be expected of the test conditions.

The total pressure profiles obtained along the minor axis of symmetry (Figure 46) show a maximum velocity of approximately the same value as was obtained from the $\phi = 0$, 45, and 90 degree planes originating at the x origin. The decay rate is lower on the minor axis plane of symmetry and the velocities are greater at greater distances above the ground plane.

Plenum Chamber - The plenum chamber was operated with a three-inch ground clearance. The machine was operated at a disk loading of 9.40 pounds per square foot (calculated using base area of 5.955 square feet) while ground total pressure profiles were taken along the major and minor axes (Figures 47 and 48 respectively). The maximum values obtained on the two axes show good agreement. The pressure at the highest points measured shows the major axis to have a thinner ground flow. The flexibility of the ground board was sufficient to account for the apparent disagreement. A .4 inch shift of the abscissa aligns the curves. To determine the effect of disk loading the plenum chamber was operated at three-inch clearance and disk loadings of 4.36 and 31.25 pounds per square foot, while pressure profiles were determined on the major axis at $a' = 0$ (Figure 49).

Annular Nozzle - The annular nozzle adapter total pressure profiles were obtained in the same manner as those for the plenum chamber. Total pressure profiles recorded along the major axis during operation at a height of three inches and a disk loading of 9.64 pounds per square foot (disk loadings based on the total areas, base plus nozzle, of 5.20 square feet) are shown in Figure 50. With the same

test conditions, profiles were obtained along the minor axis (Figure 51). The effect of disk loading is shown in Figure 52. This data was recorded along the major axis with the exit height of three inches and disk loadings of 2.31, 9.64 and 16.6 pounds per square foot. Base pressure measurements were made in one quadrant of the annular nozzle base plate under test conditions of 3-inch height and 9.64 pounds per square foot loading (Figure 53).

6.02 SOIL CONDITION I B (PLOWED LEAN CLAY)

Side by Side Ducts

The side by side ducts were tested over the plowed (flat) lean clay section at disk loadings of 15, 30, 60 and 150 pounds per square foot. Two values of Z/D (.5 and 3.0) were used, and flow rates were plotted (Figures 54 and 55 respectively). Tests conducted at Z/D = .5 show considerable erosion at a disk loading of 30 pounds per square foot (Figure 11a). The material in motion in Figure 11a appears to be

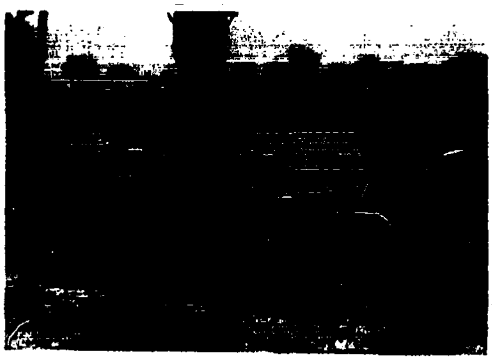


Fig. 11a. Test I B 48a During Operation

Fig. 11b. Test I B 48b After Test Completion

primarily light dust, but the eroded hole in Figure 11b shows that the heavier particles were moved out of the impact area and deposited around the eroded section. Heavy particles left on the slopes of the eroded area suggest that these larger particles were rolling or skipping along the surface.

The high disk loading (150 pounds per square foot) tests at $Z/D = .5$ shows that large particles were airborne (Figures 12a and 12b). There

Fig. 12a. Test I B 50a During Operation, Beginning of One Minute Test

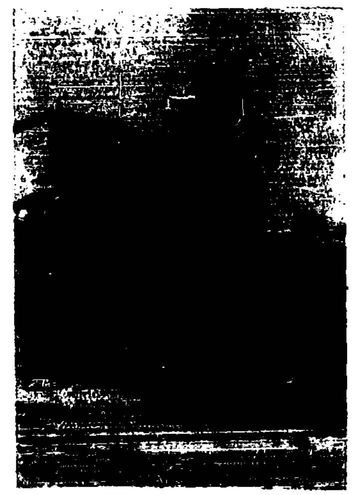


Fig. 12b. Test I B 50b During Operation, Final Period of Test

is a definite change in flow conditions with time, the particles at the start of the one-minute run being deposited over a large area (Figure 12a). During the last few seconds of the one-minute test the flow turns through a 180-degree angle and moves up very close to the diffuser (Figure 12b).

In earlier tests with the two-foot-diameter ducted fan, which had a reverse flow region at the centerline of rotation, small peaks were noted in the center of the eroded area. When air jets impinge vertically on a surface a stagnation point exists under the center of each duct. It was not conclusive whether the peaks were the result of the reverse flow or the stagnation point. A very uniform velocity profile out of the bottom of the side by side ducts was observed during the

Fig. 12c. Test I B 50c After Test Completion

initial setting of the diffuser splitter vane. The soil peaks left after completion of the tests with the side by side duct adapter (Figure 12c) are the result of the stagnation point. The eroded hole diameter versus disk loading curve (Figure 56) shows how disk loading and Z/D affect the size of the eroded area.

Plenum Chamber

At Z = .25 feet and w = 8.4 pounds per square foot (50 pounds thrust), the plenum chamber configuration showed a very definite spreading ground flow (Figure 13). The general flow pattern did not change at the highest disk loading tested (w = 31.25), see Figure 14a. The eroded section left by the plenum chamber had the same general appearance at all loadings tested. A typical example is afforded by Figure 14b. The higher loading produced deeper erosion but the center mound, roughly two feet long surrounded by a smooth trough, was the general characteristic. The flow rate profiles have been plotted for the plenum chamber and are shown in Figures 57a and 57b.

Fig. 13. Test I B 52
During Operation

Fig. 14a. Test I B 53a
During Operation

Fig. 14b. Test I B 53b After
Test Completion

Annular Nozzle

Tests of the annular nozzle showed a very positive tendency for the flow to travel through 225 degrees, and flow up along the exterior of the diffuser. Figure 15 was taken during operation at Z = .25 feet and w = 9.64 (T = 50 pounds). In contrast to the plenum chamber, which showed a spreading ground flow until the erosion formed a pocket, the annular nozzle appeared to send the dust up around the diffuser at the start of the test. At high disk loading (w = 16.6) the flow is generally the same as at lower disk loading (Figure 16a). The general drift of the dust in Figure 16a is due to a slight surface wind. The eroded area (Figure 16b) shows the steep sided trench resulting from the annular air jet.

Flow rate profiles obtained during testing of the annular nozzle were plotted (Figures 58a and 58b). The particle traps were positioned close to the exit nozzle but, due to the extreme vertical projection of material, they do not represent true indications of the material flow.

Fig. 15. Test I B 54 During Operation

Fig. 16a. Test I B 55a During Operation

Fig. 16b. Test I B 55b After Test Completion

6.03 SOIL CONDITION III A (DRY SAND)

Due to the relative uniformity and the fine grain size, the behavior of the adapters over sand provides greater understanding of the flow pattern than is possible with other soils. This would be true of the water tests but the spray hides the impingement area and the eroded section is not preserved for study after the termination of the test.

Side by Side Ducts

Because the sand was relatively dust free, the impact area could be observed during low disk loading operation. Figure 17a shows the impact area during a test at Z/D = .5 and w = 15 pounds per square foot. The sand was being swept out at a steady rate and the eroded

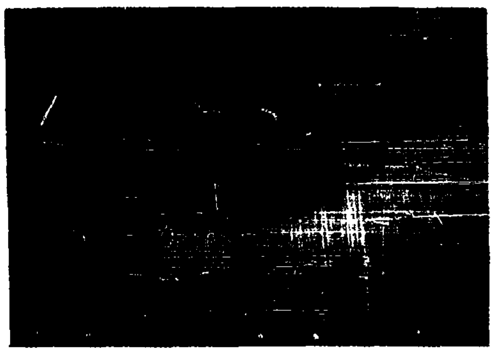


Fig. 17a. Test III A 30a During Operation

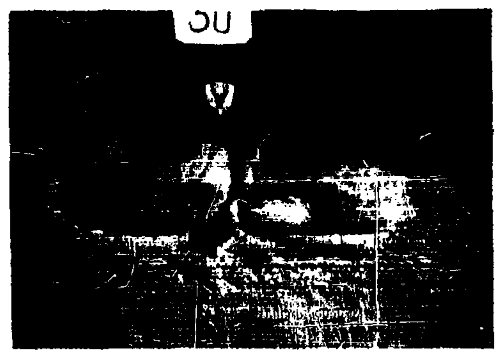


Fig. 17b. Test III A 30b After Test Completion

area shown in Figure 17b was being formed. The contact region between the two flows is relatively narrow and apparently does not influence the normal erosion pattern from Ø = 0 to beyond Ø = 90 degrees. There was no indication during this test that the flow pattern changed from a general ground flow to vertical. The eroded hole probably did not get deep enough to turn the flow up to 180 degrees.

At Z/D = .5 and w = 150 pounds per square foot the change in flow pattern was readily apparent (Figures 18a and 18b). The eroded section (Figure 18c) shows indications of moist sand in the lower regions but the general pattern is similar to that of the lower disk loading test.

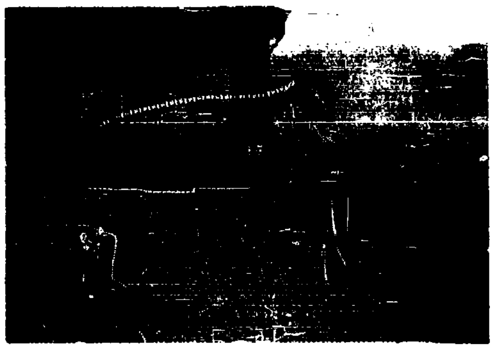


Fig. 18a. Test III A 26a During Operation, Beginning of One Minute Test

Fig. 18b. Test III A 26b During Operation, Nearing Completion of One Minute Test

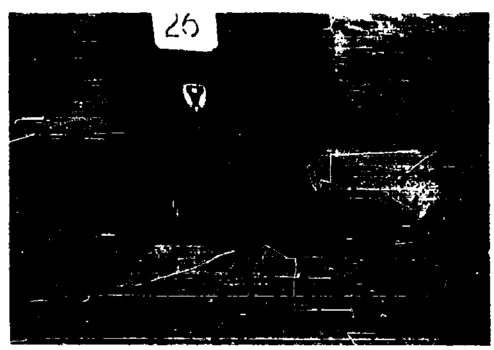


Fig. 18c. Test III A 26c, After Test Completion

The overall appearance of the high Z/D tests (Z/D = 3) was essentially the same as the low Z/D tests with the exception that the airborne sand had the appearance of being caused by larger geometry machinery (Figures 19a and 19b). By comparing the eroded section (Figure 19c)

Fig. 19a. Test III A 39a During Operation, Beginning of 45 Second Test

Fig. 19b. Test III A 39b During Operation, Nearing Completion of 45 Second Test

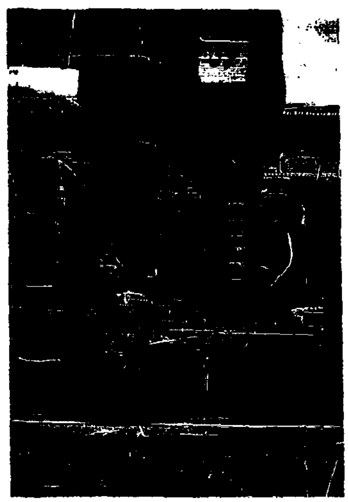


Fig. 19c. Test III A 39c After Test Completion

with the low Z/D tests it will be seen that the eroded holes have more overlap at Z/D = 3, which leaves a single ridge near the geometric center with less definite traces of the double ridge so evident at

lower Z/D range. Some of the loss in the double ridge in Figure 18c is due to the depth of the hole. Comparison of Figure 17b with Figure 20, both of which were tested at a disk loading of 15 pounds per square foot and a test time of one minute, shows the lack of sharpness in the ridges at high Z/D.

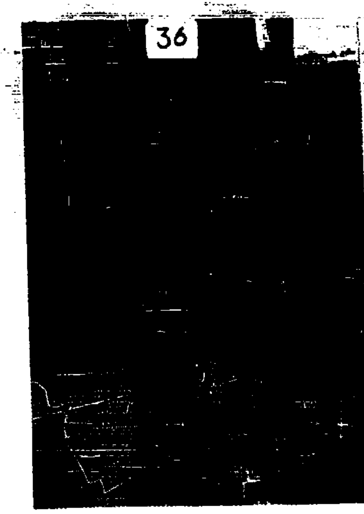


Fig. 20. Test III A 36 After Test Completion

The tests of the side by side ducts appeared to produce more vertical projection of the airborne material than was observed in earlier tests of the single two-foot duct. The test condition represented by Z/D = 1.5 and w = 60 pounds per square foot was chosen for a more detailed investigation. A rapid change from ground flow to vertical projection started at about 48 seconds after full rpm was reached, and complete vertical projection was established at 50 seconds when tests were terminated. The ground flow and the spurting along the contact region between the two flows can be seen in Figure 21a.

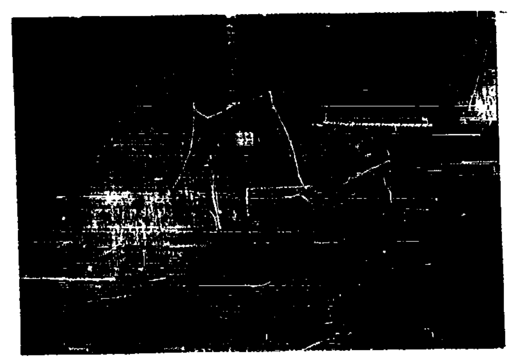


Fig. 21a. Test III A 33a, During Operation, Beginning of 50 Second Test

The typical eroded section (Figure 21b) shows a damp sand area under one duct. It is interesting to note that the contact region is shifted slightly away from the damp side of the hole. It was suspected that the presence of the adapter plate could be responsible for the vertical projection of material. The ducts were extended from the original 8-inch length to 26½ inches. The resulting eroded section is shown in Figure 22. The test time prior to vertical projection of material and total test time was identical to that in Figure 21. It was concluded that the vertical projection not observed to such an extent in the two-foot duct tests was the result of the side by side duct configuration.

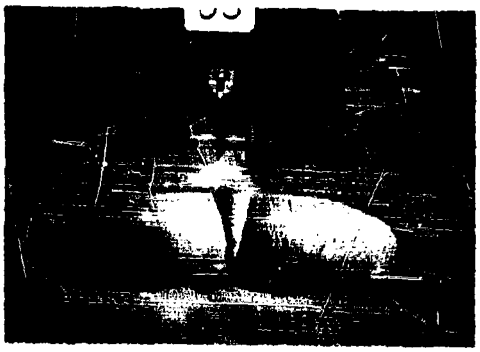


Fig. 21b. Test III A 33b After Test Completion

Fig. 22. Test III A 41 After Test Completion

To avoid recalibration necessary if one duct were plugged, a box was constructed to divert the flow from one duct. Figure 23a was taken after the first few seconds of operation. Figure 23b was taken after approximately 49 seconds, and the eroded hole (Figure 23c) shows the results of

Fig. 23a. Test III A 46a During Operation, Beginning of 50 Second Test

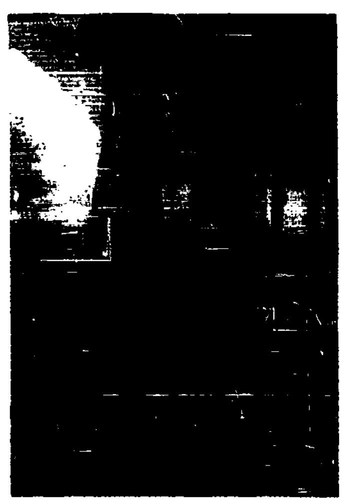


Fig. 23b. Test III A 46b During Operation, Nearing Completion of 50 Second Test

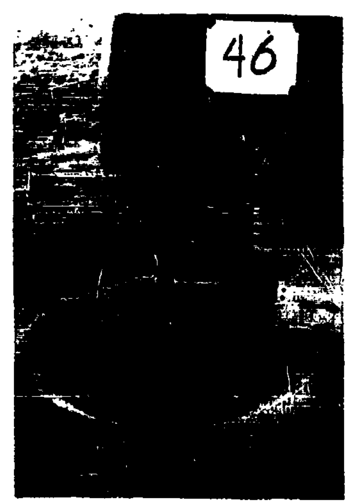


Fig. 23c. Test III A 46c After Test Completion

the test. The test time required to start the vertical projection and total test time required to produce the complete flow change was identical to that in Figure 21.

The eroded section profile was obtained for tests III A 31, III A 32, III A 33, III A 41 and III A 46. The profile for Z/D = 1.5 and w = 15, 30, and 60 pounds per square foot is shown in Figure 59 and the profile for the three tests at Z/D = 1.5 and w = 60 pounds per square foot is shown in Figure 60. These profiles were numerically integrated to obtain the total material which would have been removed if the depression were a full 360-degree rotation of the profile. A curve of the total erosion rate versus disk loading was plotted assuming a single hole based on the above assumption (Figure 61). The flow rate profiles have been plotted for the side by side ducts and Z/D = .5 (Figure 62), Z/D = 1.5 (Figure 63), and Z/D = 3.0 (Figure 64). The relative diameter of one of the pair of eroded holes has been plotted versus disk loading (Figure 65).

Plenum Chamber

Tests over sand showed the plenum chamber configuration to produce very low ground projection of the airborne sand. Figure 24a was obtained

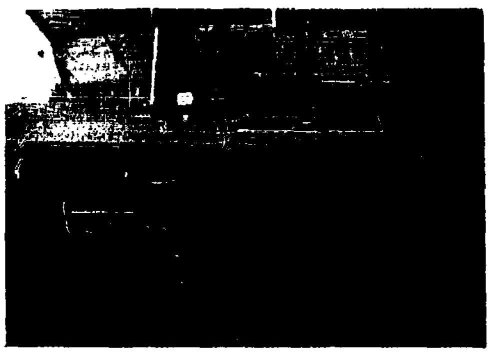


Fig. 24a. Test III A 58a During Operation

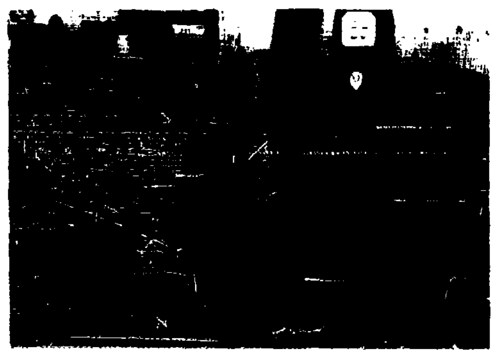


Fig. 24b. Test III A 58b After Test Completion

during a test at w = 8.40 pounds per square foot but it is typical of all disk loadings tested, as is the smooth contour of the eroded section (Figure 24b). The plenum chamber showed a tendency to produce

an eroded hole similar to that of the side by side ducts. Figure 25 shows a slight double ridge on the minor axis of the eroded section. This test was a one-minute test at a disk loading of 31.25 pounds per square foot.

Fig. 25. Test III A 59 After Test Completion

Flow rate profiles were obtained for the plenum chamber at disk loadings of 8.4 and 31.25 pounds per square foot (Figures 66a and 66b respectively).

Annular Nozzle

The annular nozzle configuration produced typical high projection of the sand (Figure 26a) with a disk loading of 9.64 pounds per square foot.

Fig. 26a. Test III A 56a During Operation One Minute Test

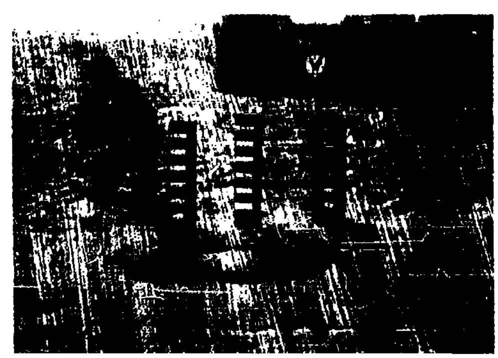


Fig. 26b. Test III A 56b After Test Completion

The test at a disk loading of 16.6 pounds per square foot was similar except that the sand cloud was much denser and the trench produced was deeper than that of the lower disk loading test (Figure 26b). The flow rates have been plotted (Figures 67a and 67b) but, as previously stated, the high vertical projection prevented capture of representative quantities of material.

6.04 SOIL CONDITION IV A (GRAVEL)

The general characteristics of the sand tests were also typical of the gravel tests, except that the disk loading required to move the gravel was higher than that for the other soils.

Side by Side Ducts

The side by side ducts are shown during operation (Figures 27a and 27b) at $Z/D = .5$ and $w = 150$ pounds per square foot.

Fig. 27a. Test IV A 66a During Operation, Initial Few Seconds of Test

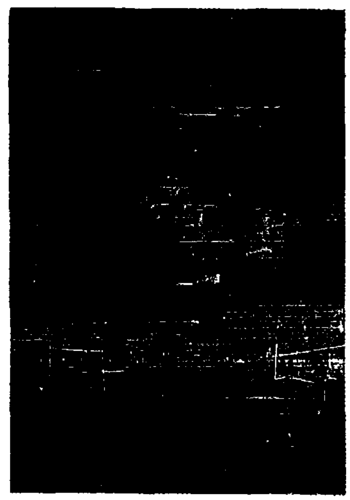


Fig. 27b. Test IV A 66b During Operation, Last Few Seconds of Test

The eroded hole (Figure 27c) has the same general shape as was produced over the sand; however, the features are not as predominant due to the roughness of the surface. Flow rate profiles are shown for Z/D = .5 in Figure 68 and for Z/D = 3 in Figure 69. The ratio of the equivalent hole diameter to the duct exit diameter was plotted versus disk loading for the gravel tests (Figure 70).

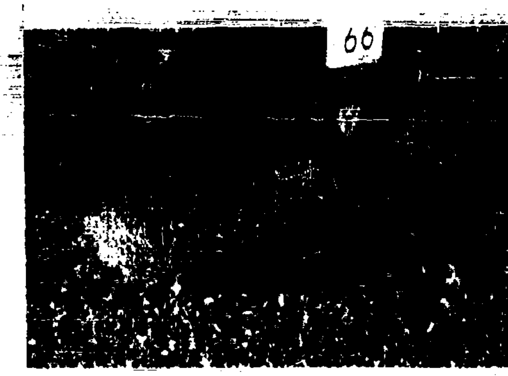


Fig. 27c. Test IV A 66c After Completion of 10 Second Test

Plenum Chamber

The tests of the plenum chamber at w = 8.40 pounds per square foot produced very little activity in the gravel as can be seen from the flow rate profiles (Figure 71a). The higher disk loading (w = 31.25 pounds per square foot) produced considerable soil movement (Figure 28) and the particle traps reflect the increased activity in the flow rate profiles (Figure 71b).

Fig. 28. Test IV A 61 After Test Completion of One Minute Test

Annular Nozzle

The annular nozzle showed considerably more activity at low disk loading ($w = 6.40$ pounds per square foot) than was shown by the plenum chamber. Figure 29 shows the results of a one-minute test at $w = 6.4$ pounds per square foot. For comparison purposes the erosion caused by a one-minute test at $w = 16.6$ pounds per square foot is shown in Figure 30. The island left in the center (Figure 30) shows light sand and gravel on the surface, while the trench shows only large particles swept clean of sand and light gravel. Outside the trench the particles become smaller at greater distances. These are the particles that fell back to the surface. The dust and light sand were carried off while light gravel went up two to four feet and fell back. The flow rate profiles are shown in Figure 72.

Fig. 29. Test IV A 62 After Completion of One Minute Test

Fig. 30. Test IV A 63 After Completion of One Minute Test

6.05 SOIL CONDITION V A (WATER)

Side by Side Ducts

The side by side ducts were tested over the water at Z/D ratios of .5, 1.5 and 3 and at disk loadings of 8, 15, 30, 60, 100, and 150 pounds per square foot. The general spray pattern produced was similar to the airborne sand pattern. At low disk loading where the impact area could be observed, the contact region produced a spray plane on the minor axis of the twin duct system (Figure 31). At the high disk loading conditions the excessive spray made observation of the impact region impossible (Figure 32). The change from low surface flow to

Fig. 31. Test V A 9
Side by Side Ducts
Z/D = 3 w = 15

Fig. 32. Test V A 19
Side by Side Ducts
Z/D = 1.5 w = 150

vertical flow was not as noticeable with the water tests as it was

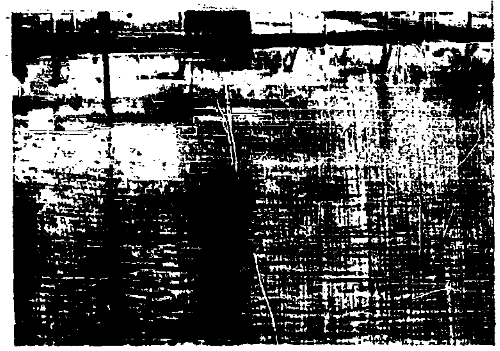
Fig. 33. Test V A 15
Side by Side Ducts
Z/D = 1.5 w = 15

Fig. 34. Test V A 17
Side by Side Ducts
Z/D = 1.5 w = 60

with the sand tests; however, comparison between the spray from a test at w = 15 pounds per square foot (Figure 33) and one at w = 60 pounds per square foot (Figure 34) shows the overall flow change.

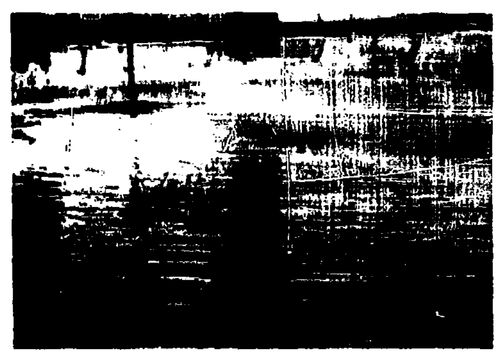
The spray height increases with increasing disk loading at constant Z/D, and at constant disk loading the spray height increases with Z/D (Figure 35 - see next three pages). It can be seen from these that at times the photographs were taken before the waves had propagated across the pond. The wave rod traces, however, were always made after conditions were stabilized. The data obtained from the wave rods has been reduced and profile plots of surface displacement versus radius ratio were constructed for: Z/D = .5 (Figure 73), Z/D = 1.5 (Figure 74), and Z/D = 3 (Figure 75). The primary wave amplitude (Figure 76) and wave frequency (Figure 77) were plotted versus disk loading for each of the five wave rods located as shown in Figure 40.

Test V A 20 Side by Side Ducts
Z/D = .5 w = 8



Test V A 8 Side by Side Ducts
Z/D = 3 w = 8

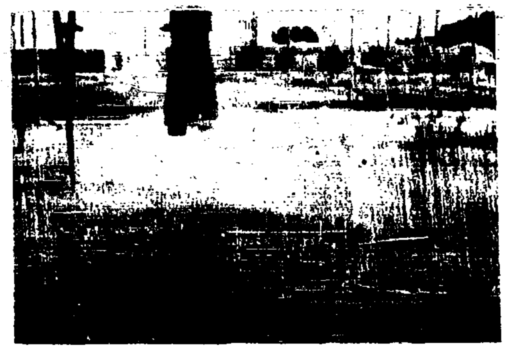
Test V A 21 Side by Side Ducts
Z/D = .5 w = 15



Test V A 9 Side by Side Ducts
Z/D = 3 w = 15

Fig. 35
Comparison of V A Tests With
Side by Side Ducts, Variable Z/D and w

Test V A 22 Side by Side Ducts
Z/D = .5 w = 30

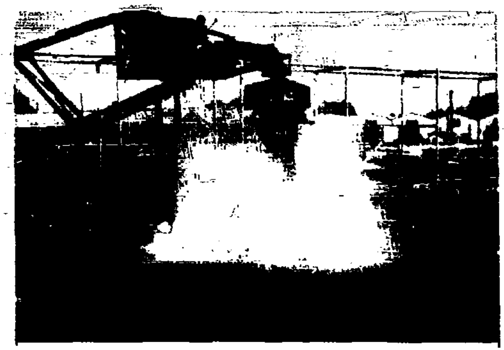


Test V A 10 Side by Side Ducts
Z/D = 3 w = 30

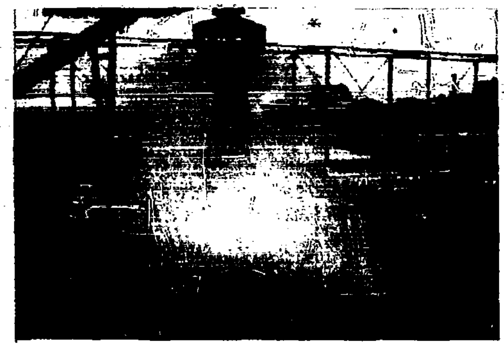
Test V A 23 Side by Side Ducts
Z/D = .5 w = 60

Test V a 11 Side by Side Ducts
Z/D = 3 w = 60

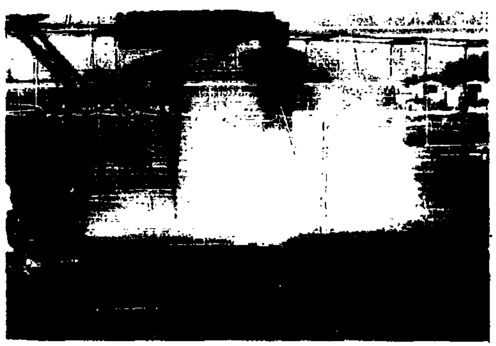
Fig. 35
(Continued)



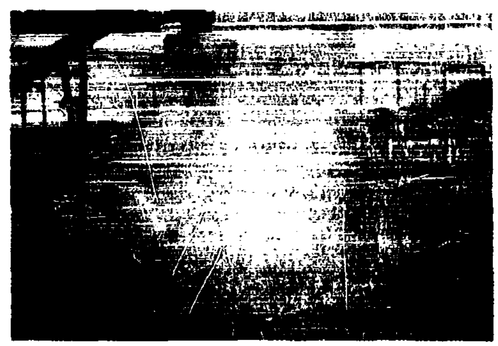
Test V A 24 Side by Side Ducts
Z/D = .5 w = 100



Test V A 12 Side by Side Ducts
Z/D = 3 w = 100



Test V A 25 Side by Side Ducts
Z/D = .5 w = 150



Test V A 13 Side by Side Ducts
Z/D = 3 w = 150

Fig. 35
(Continued)

Plenum Chamber

While the plenum chamber was in operation it was possible to observe the water surface in the plenum area. The water surface in this area was below the mean water level, but its surface was quite smooth with waves beginning in the area of the change in surface elevation and propagating outward. At the highest disk loading tested the spray, although quite dense, stayed near the surface. The set of photographs (Figures 36a, b and c) shows the plenum chamber in operation at the disk loadings tested (w = 4.36, 8.40 and 31.25) over the water. The

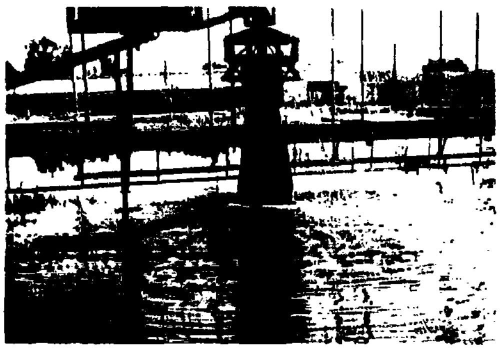


Fig. 36a. Test V A 7 Plenum Chamber w = 4.36

Fig. 36b. Test V A 6 Plenum Chamber w = 8.40

Fig. 36c. Test V A 4 Plenum Chamber w = 31.25

wave rod location was as depicted in Figure 41. The surface displacement (Figure 78), wave amplitude (Figure 79), and the wave frequency curves (Figure 80) were plotted using the same type of plots as was used with the side by side ducts.

Annular Nozzle

The annular nozzle projected the spray almost vertically, even at the very low disk loading of 2.31 pounds per square foot. Large drops were lifted four to six inches above the water surface (Figures 37a, b and c). The water under the base plate appeared to be much rougher

Fig. 37a. Test V A 3 Annular Nozzle w = 2.31

Fig. 37b. Test V A 2 Annular Nozzle w = 9.64

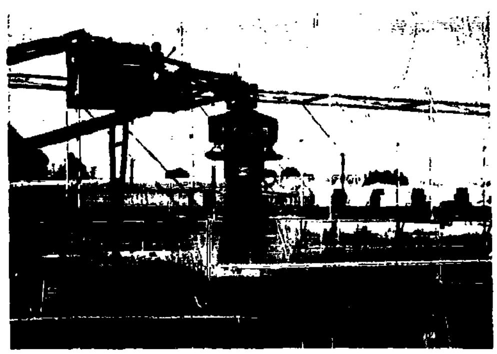


Fig. 37c. Test V A 1 Annular Nozzle w = 16.6

than that under the plenum chamber, and the overall spray was greater, at the same thrust, for the annular nozzle. The series of photographs shows the plenum chamber configuration in operation at w = 2.31, w = 9.64 (T = 50 pounds) and w = 16.6 pounds per square foot. Wave rods were located as shown in Figure 42. The surface displacement (Figure 81), wave amplitude (Figure 82), and wave frequency curves (Figure 83) were prepared in the same manner as those for the side by side ducts.

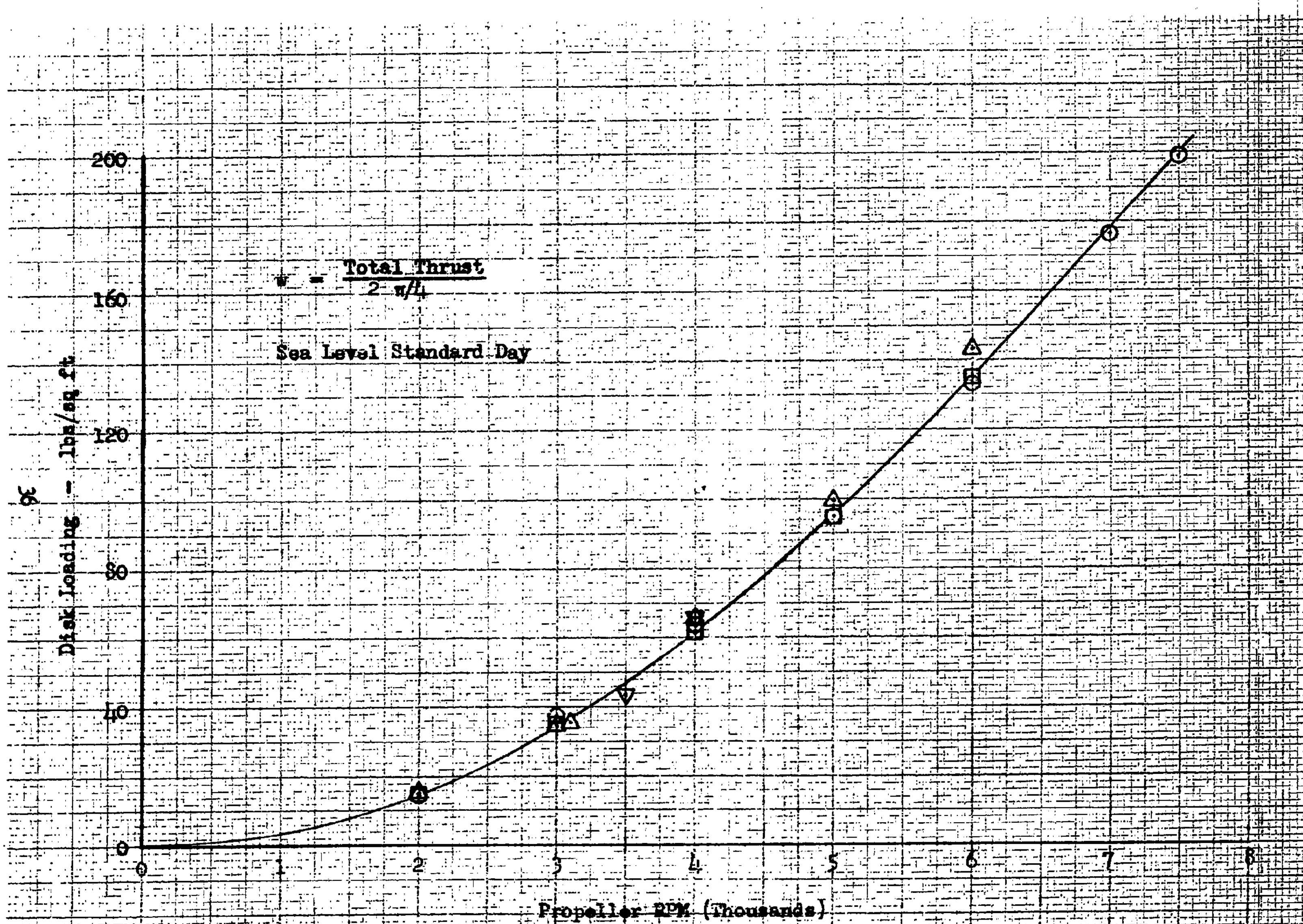


Figure 38 Disk Loading vs RMP
Side by Side Ducts

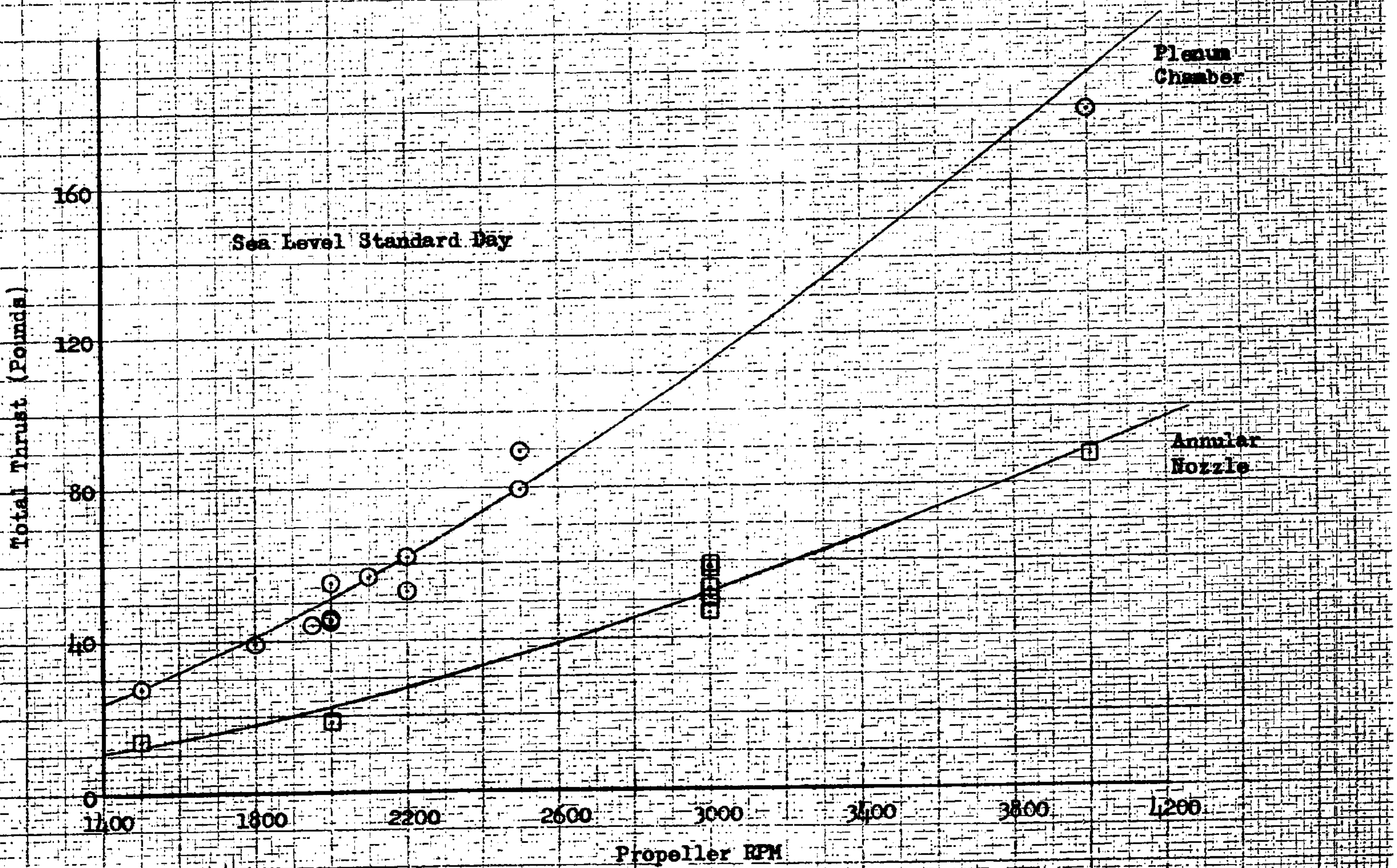


Figure [illegible] Ground Effect Machine Duct Adapter Thrust vs RPM

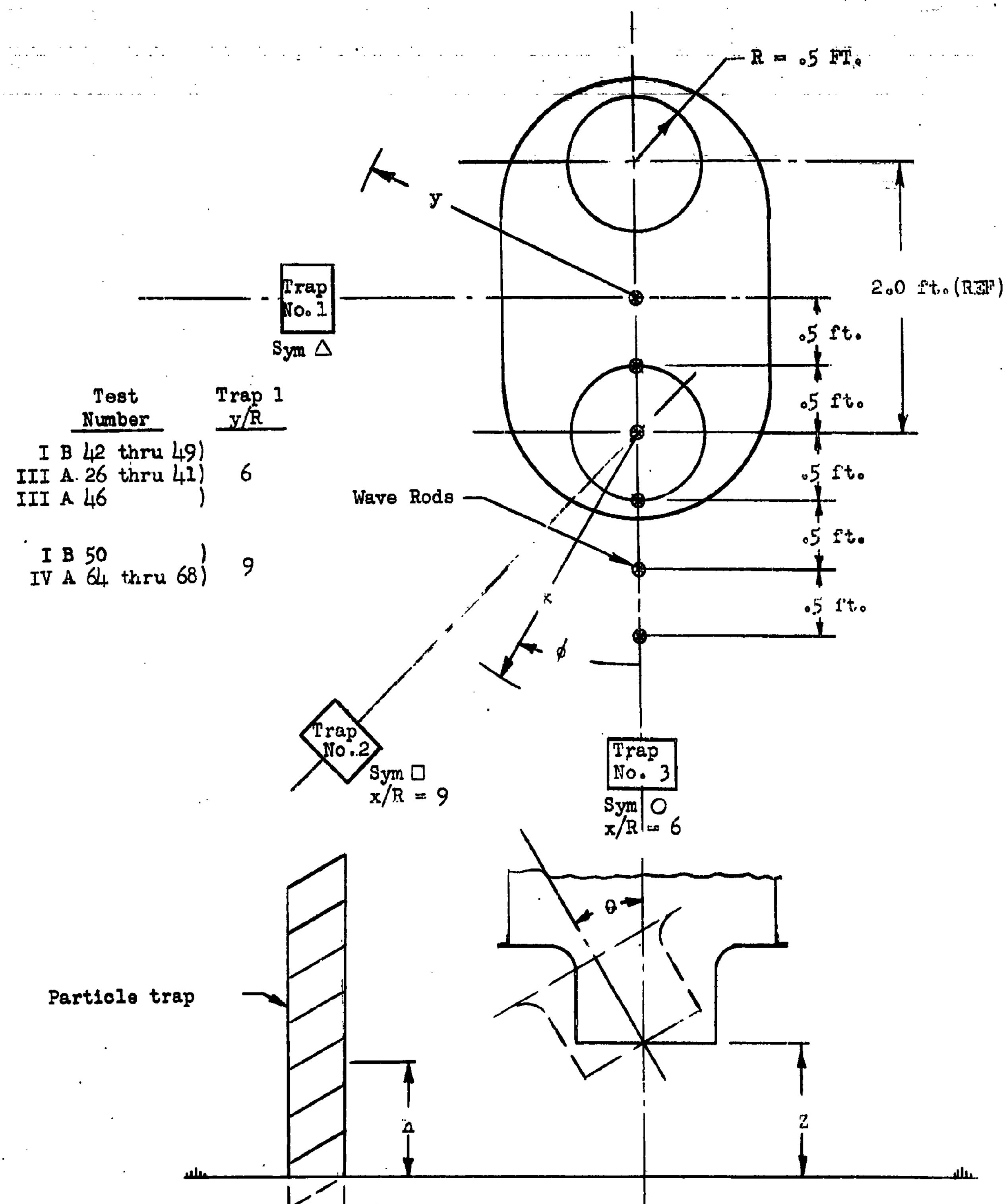
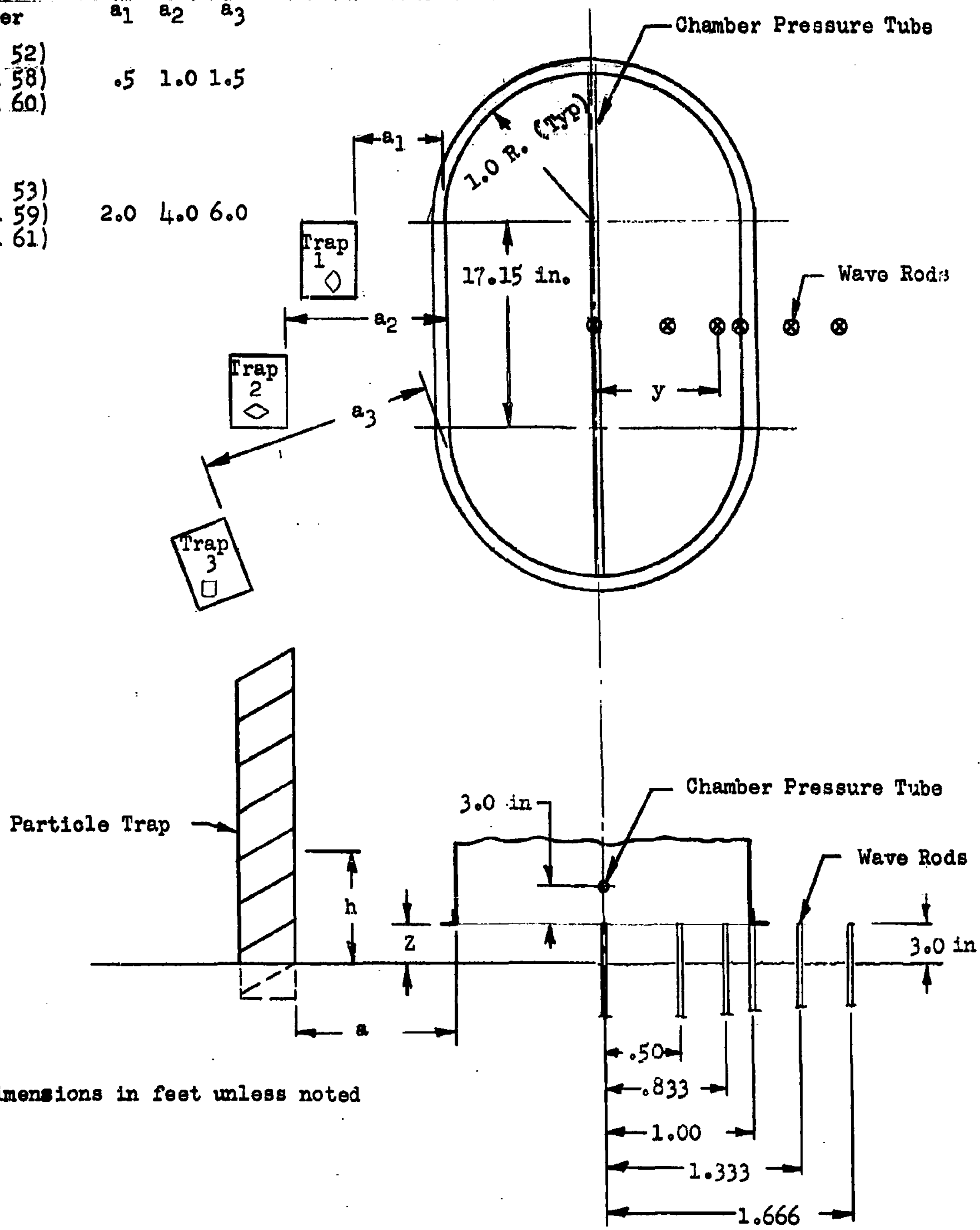


Figure 40 General Arrangement, Test Equipment, Side by Side Flow Adapter

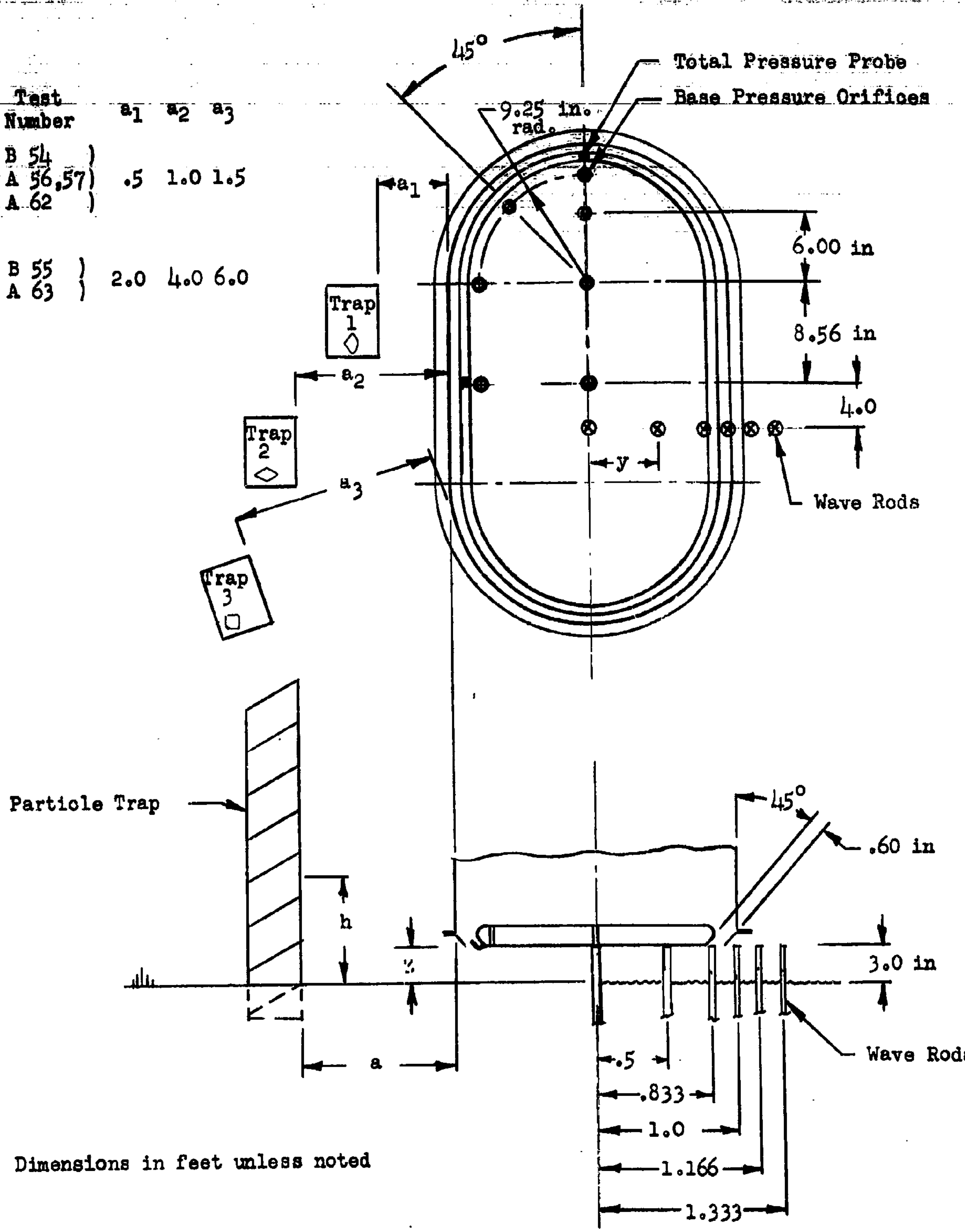
Test Number	a_1	a_2	a_3
I B 52) III A 58) IV A 60)	.5	1.0	1.5
I B 53) III A 59) IV A 61)	2.0	4.0	6.0



NOTE: Dimensions in feet unless noted

Figure 41 General Arrangement, Test Equipment
Plenum Chamber

Test Number	a_1	a_2	a_3
I B 54, III A 56,57, IV A 62	.5	1.0	1.5
I B 55, IV A 63	2.0	4.0	6.0



NOTE: Dimensions in feet unless noted

Figure 42 General Arrangement, Test Equipment Annular Nozzle Flow Adapter

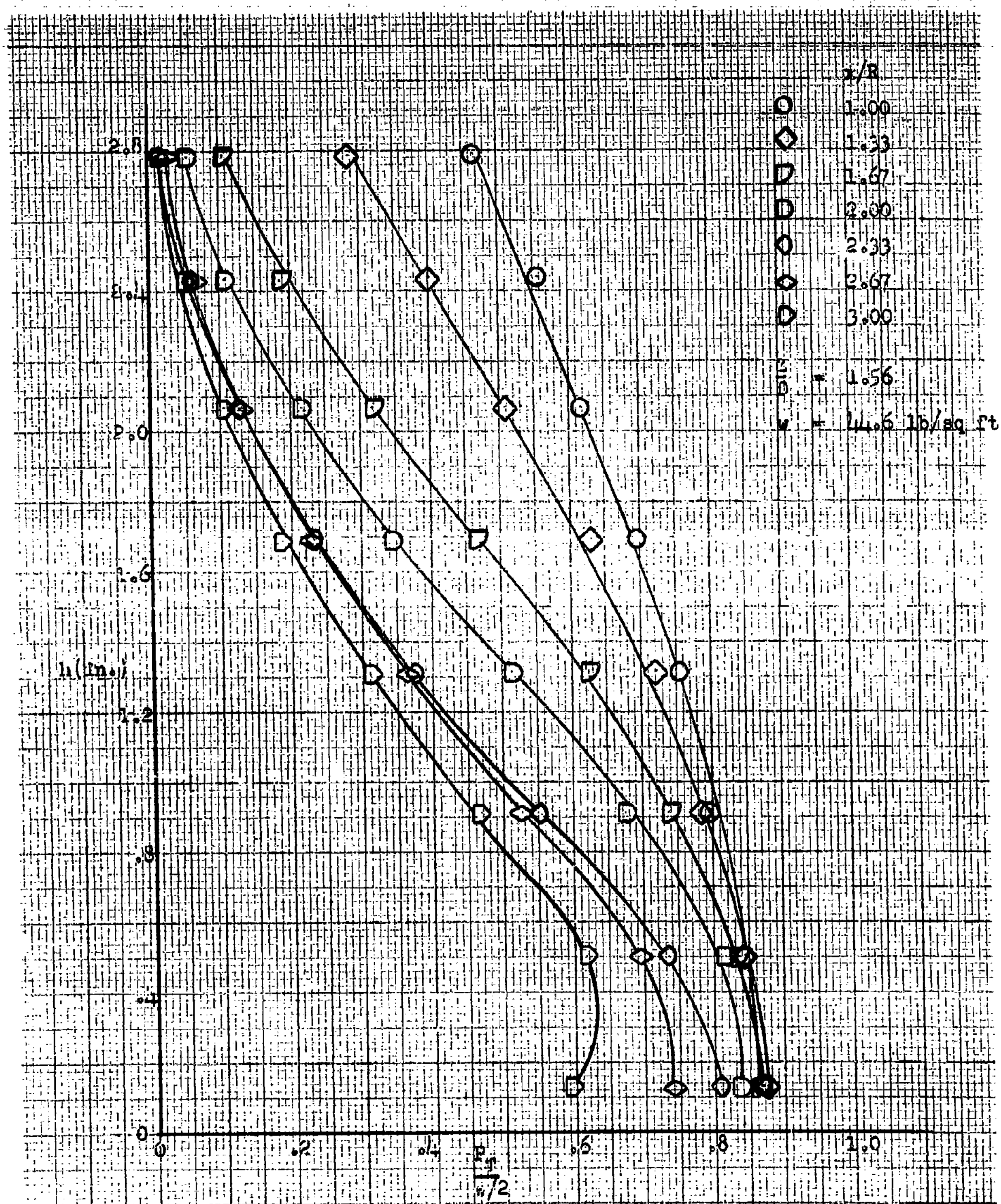


Figure 43 Side by Side Ducts Total Pressure Profile
ϕ = 0° (major axis)

E-12D

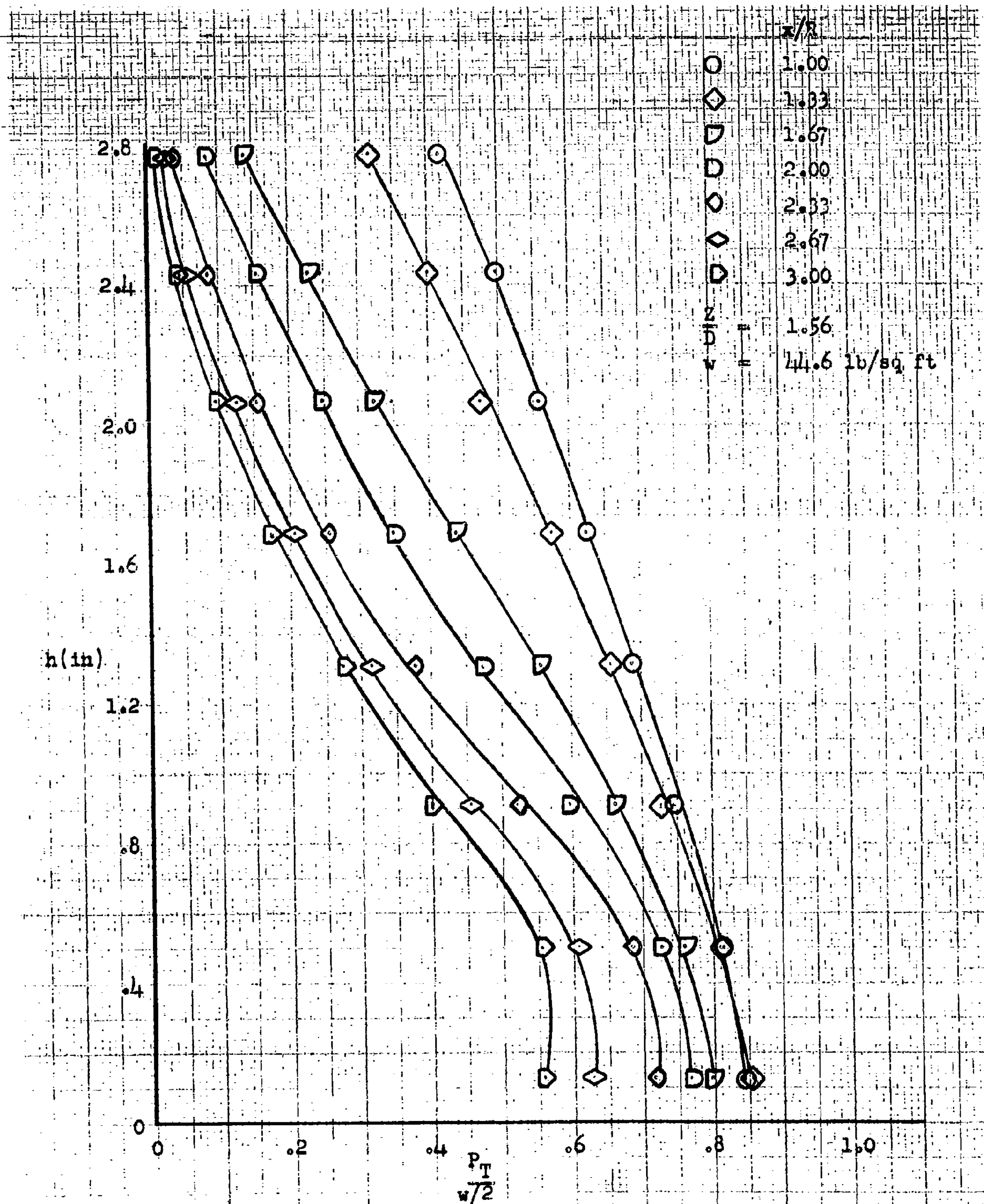


Figure 44 Side by Side Ducts Total Pressure Profiles

$\phi = 45°$

E-128

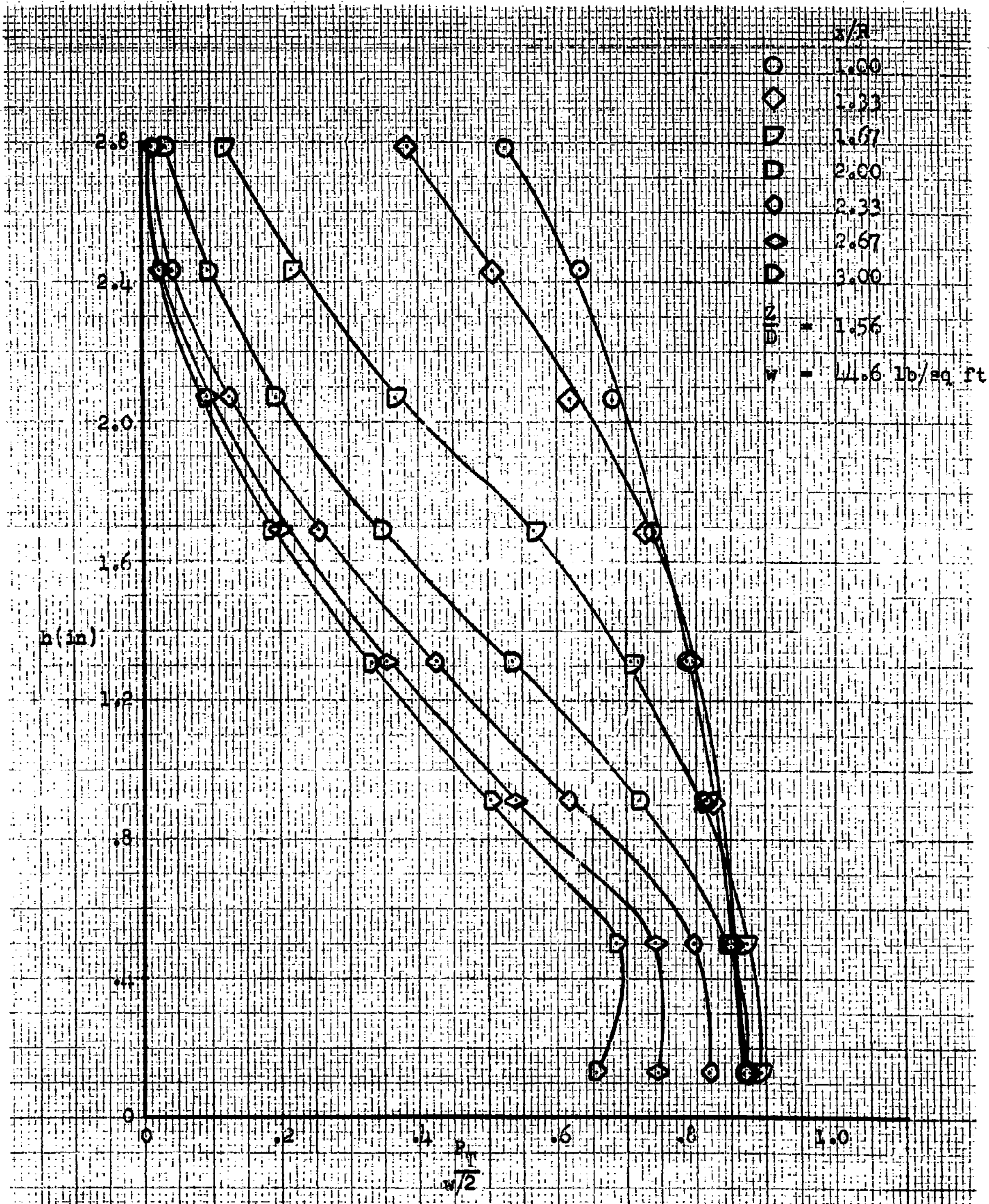


Figure 45 Side by Side Ducts Total Pressure Profiles

$\phi = 90^\circ$

E-12D

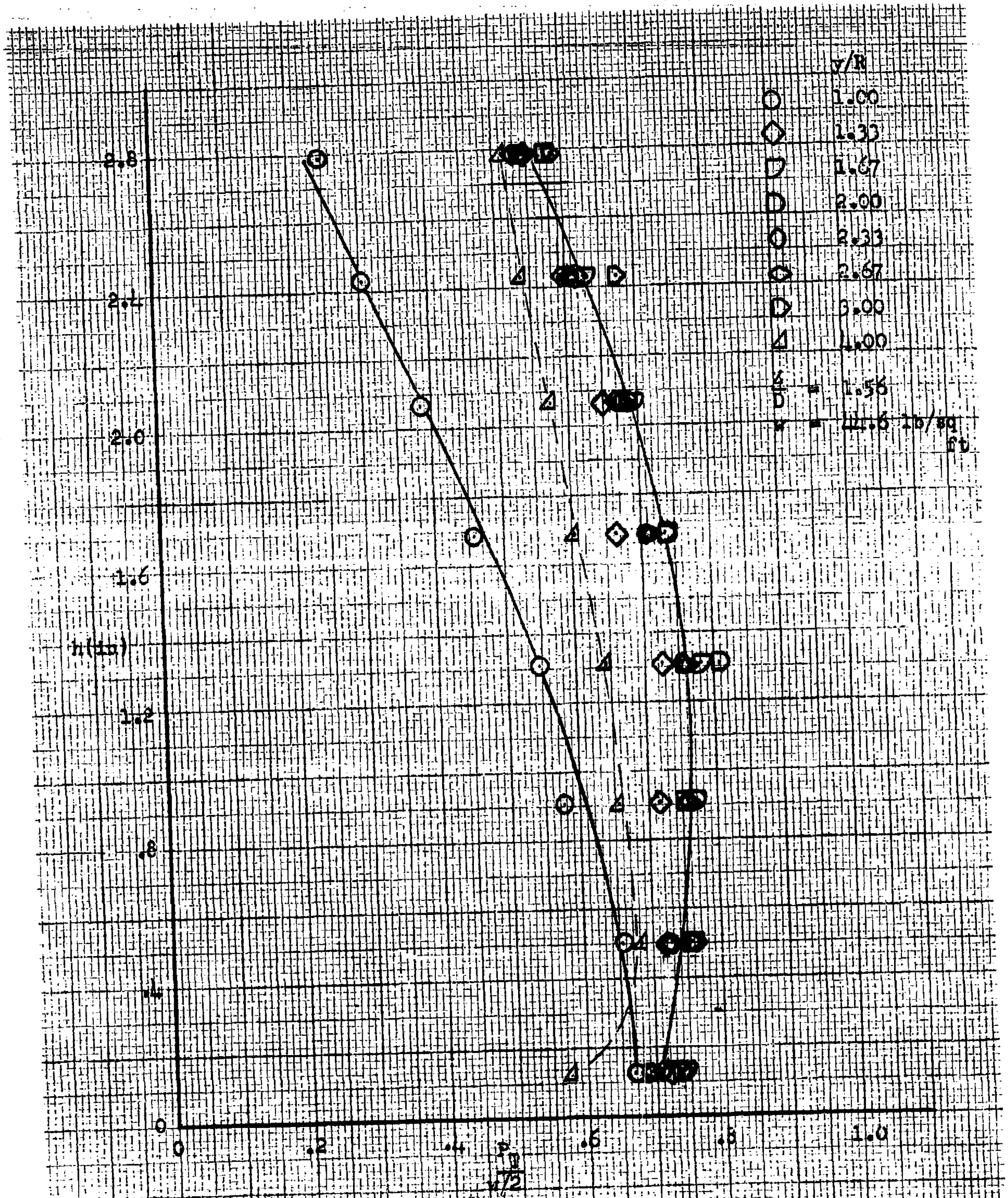


Figure 46 Side by Side Ducts Total Pressure Profile
[redacted]

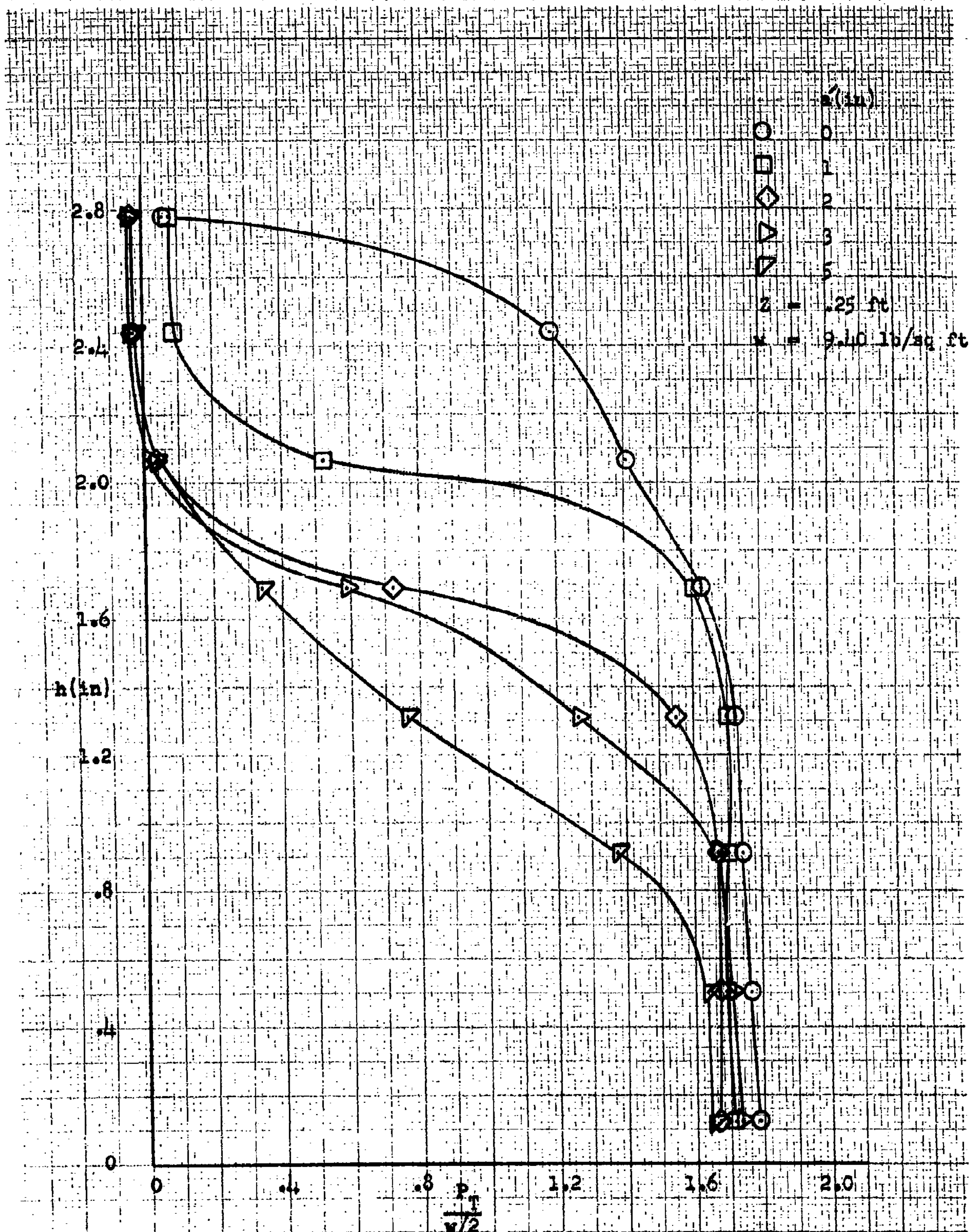


Figure 47 Plenum Chamber Total Pressure Profiles
$\phi = 0^\circ$ (major axis)

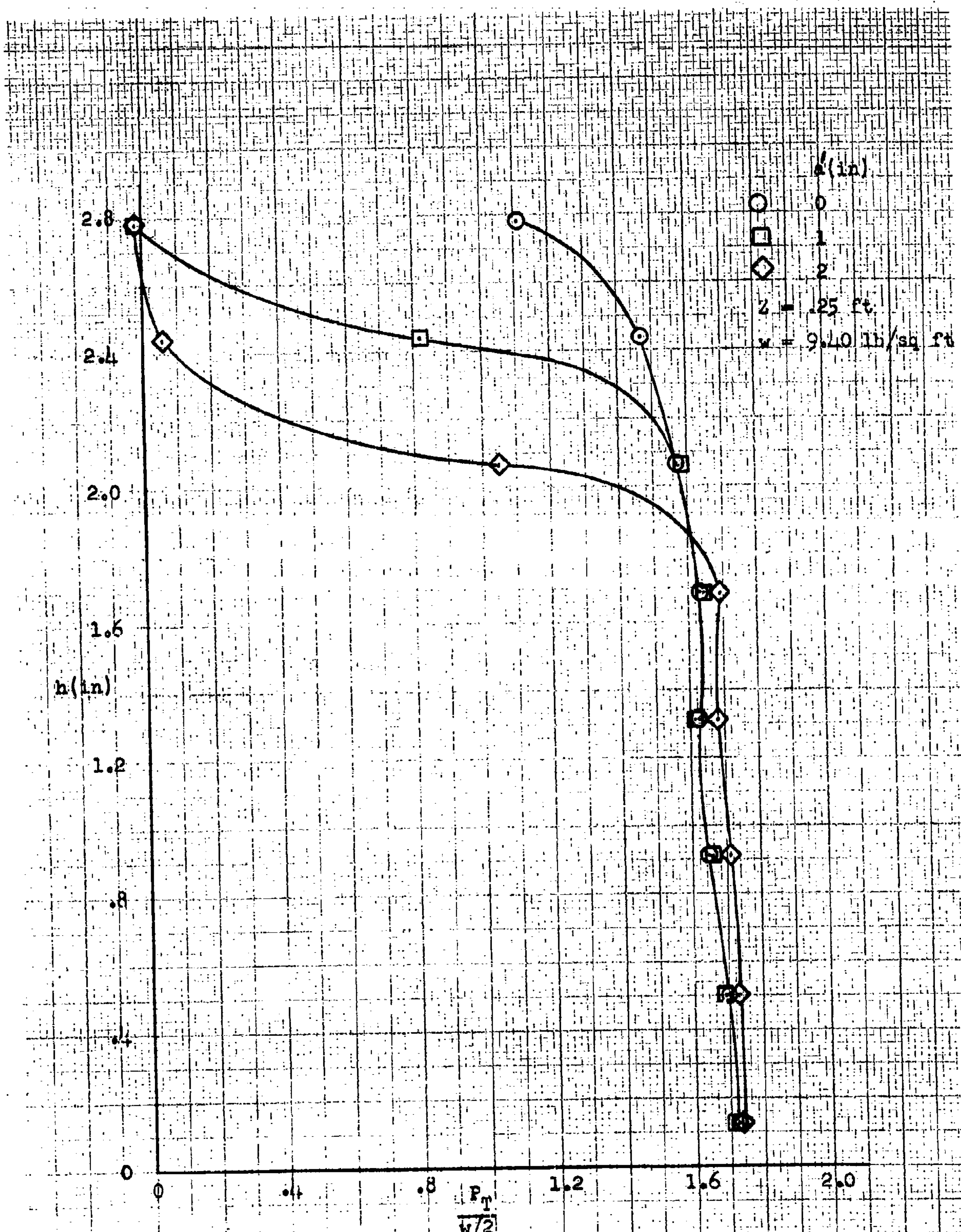


Figure 48 Plenum Chamber Total Pressure Profiles
$\phi = 90^{\circ}$ (minor axis)

E-12D

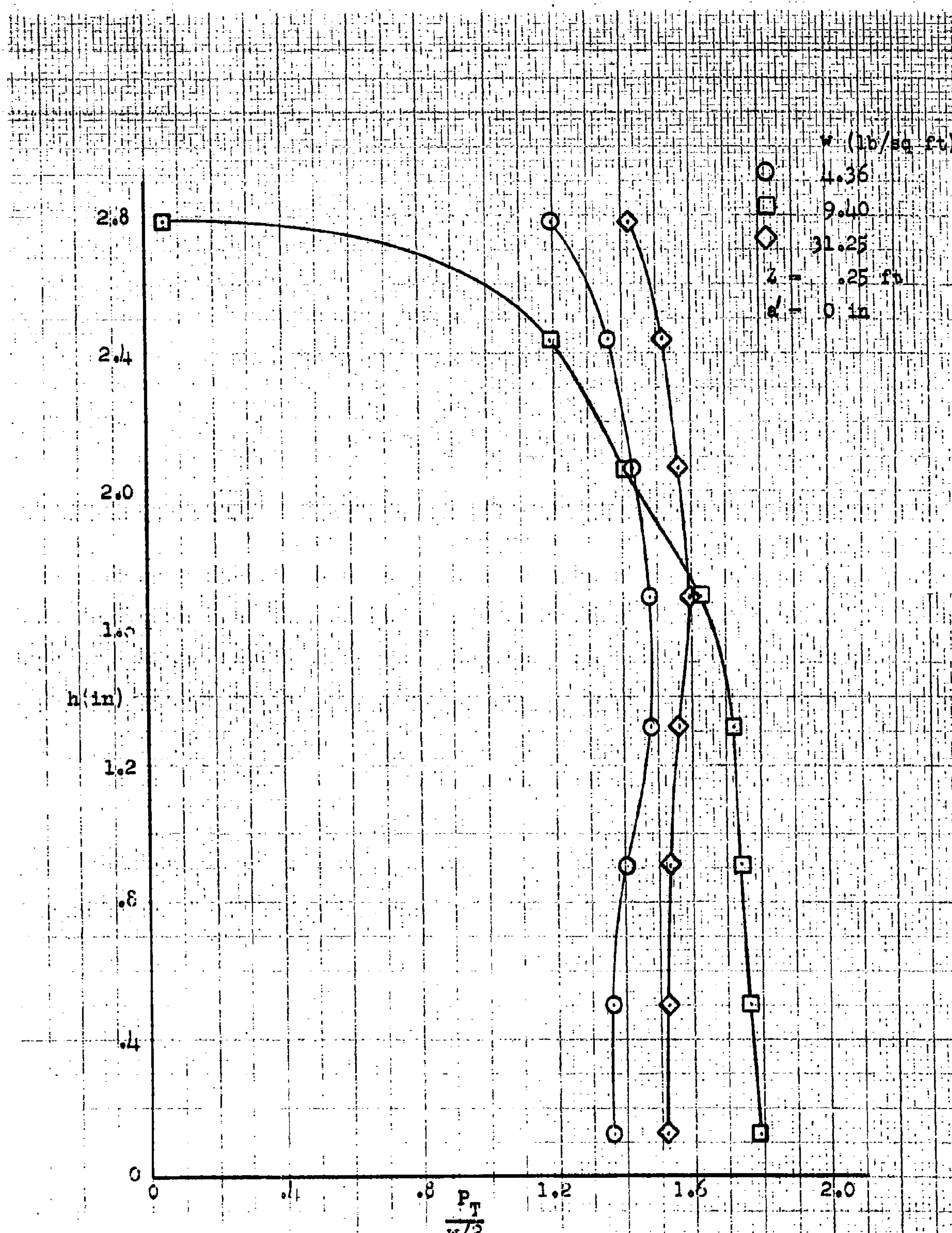


Figure 49 Plenum Chamber Effect of Disk Loading on Total Pressure Profiles $\phi = 0^{\circ}$ (major axis)

E-12D

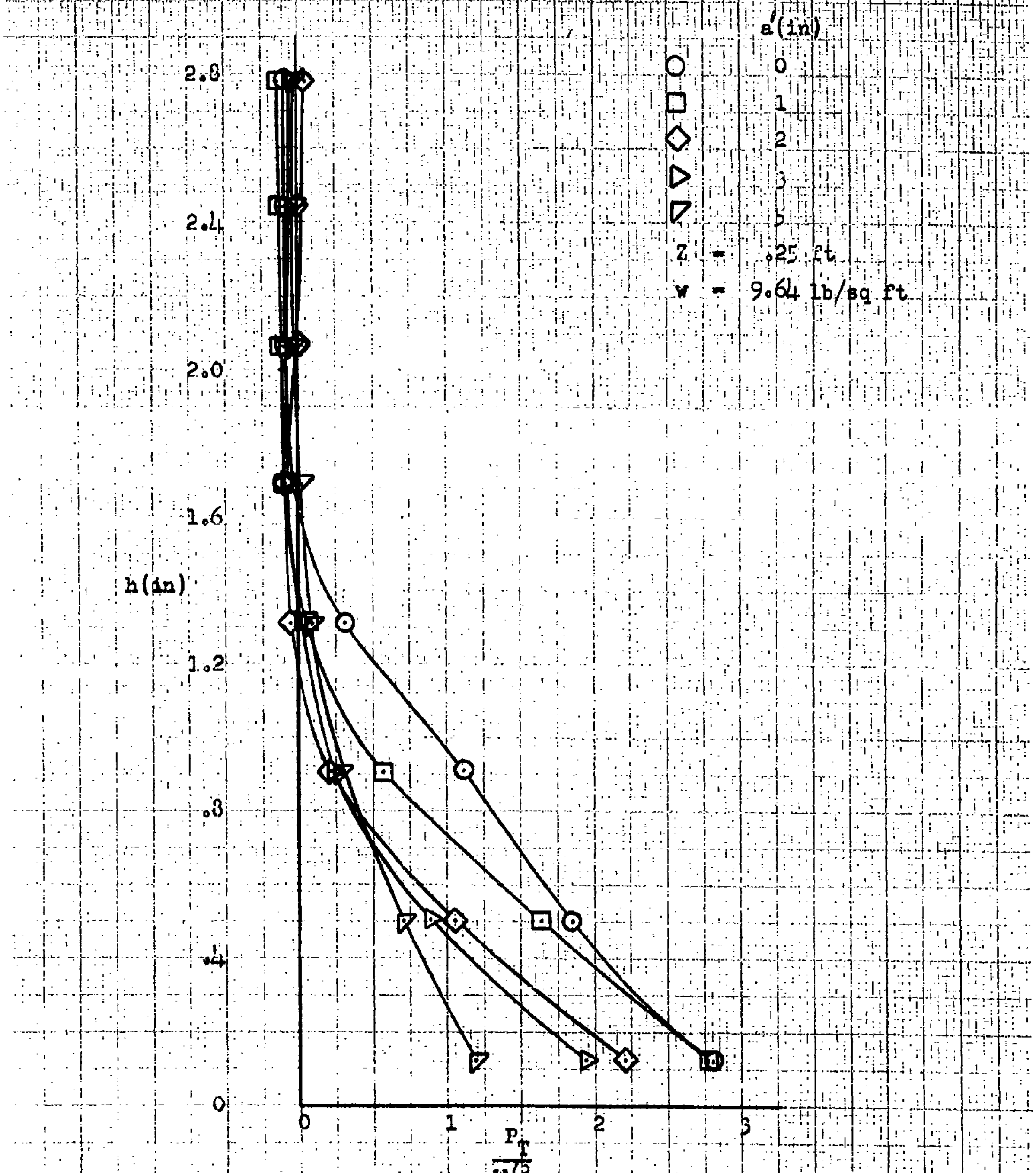


Figure 50 Annular Nozzle, Total Pressure Profiles
$\phi = 0^{\circ}$ (major axis)

E-12D

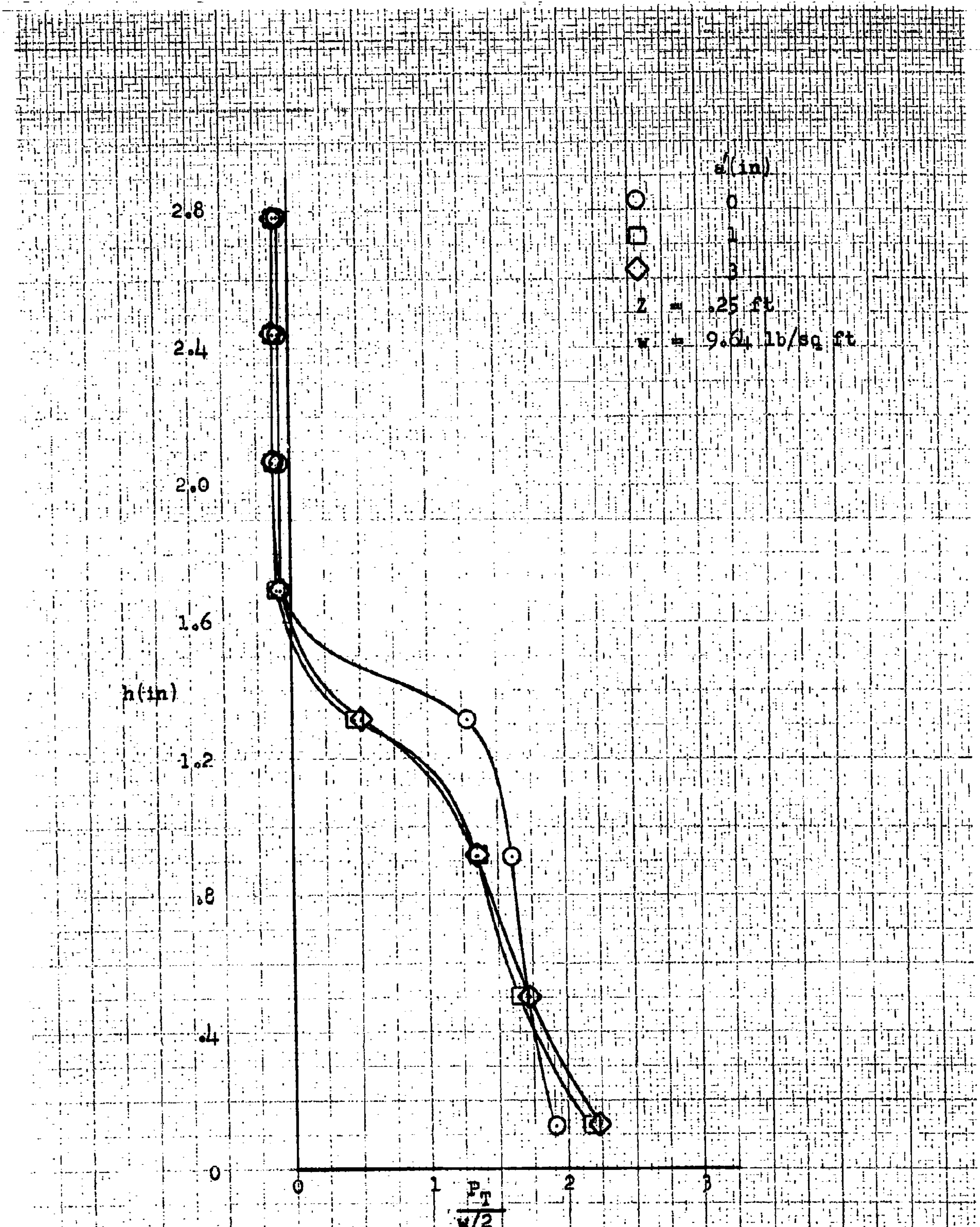


Figure 51 Annular Nozzle, Total Pressure Profiles
ϕ = 90° (minor axis)

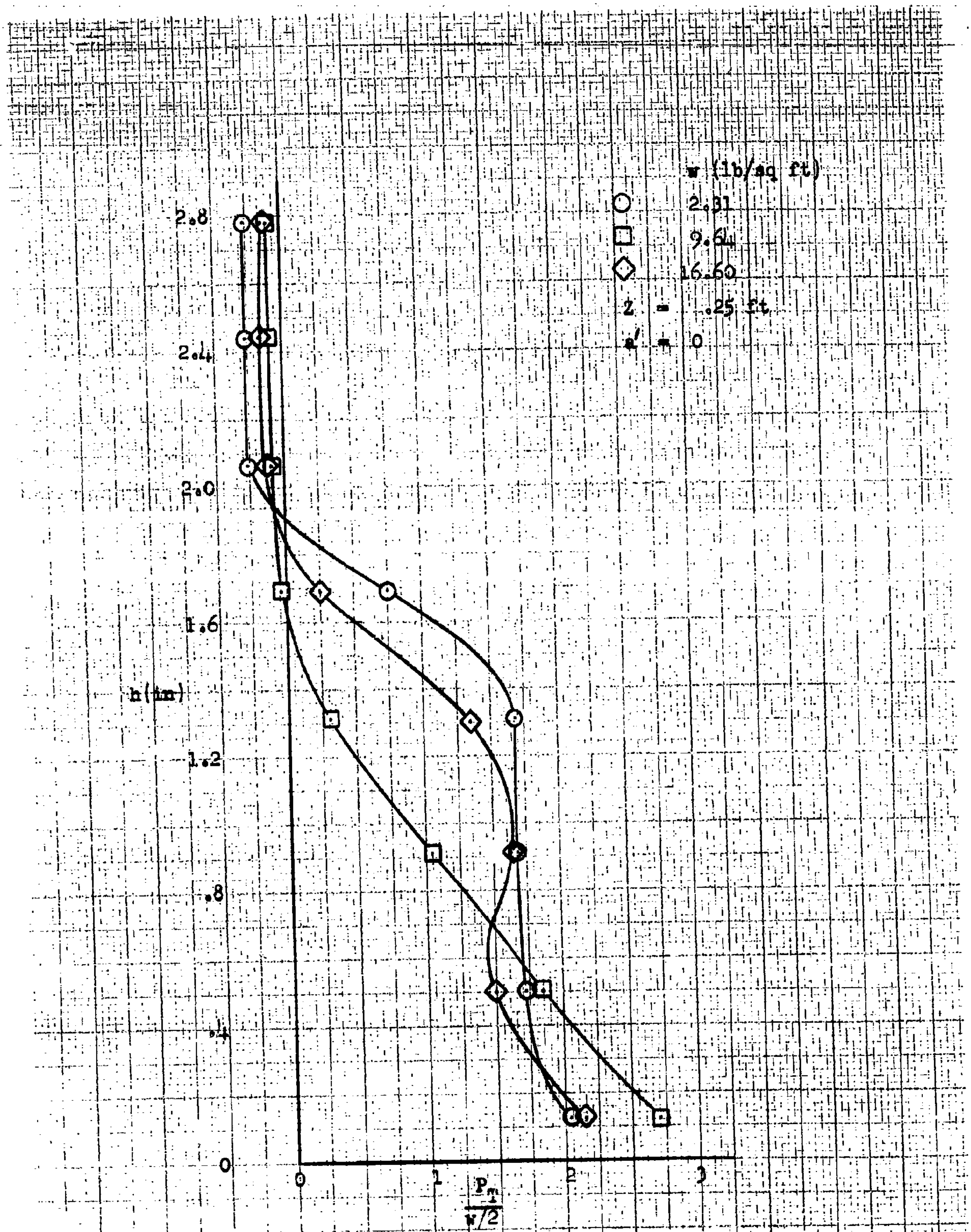


Figure 52 Annular Nozzle, Total Pressure Profiles

$\phi = 0^{\circ}$ (major axis)

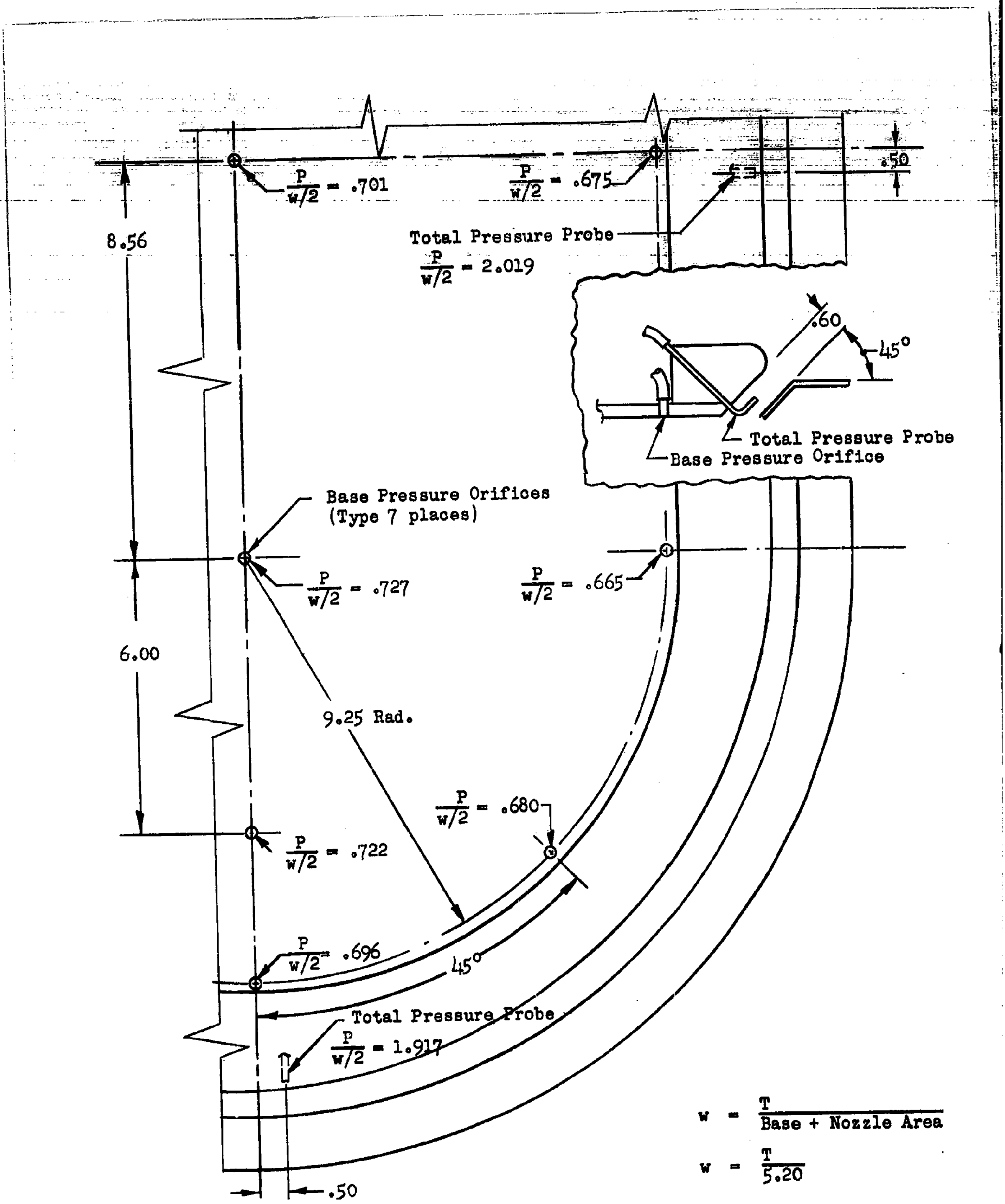


Figure 53 Annular Nozzle Pressure Measurements

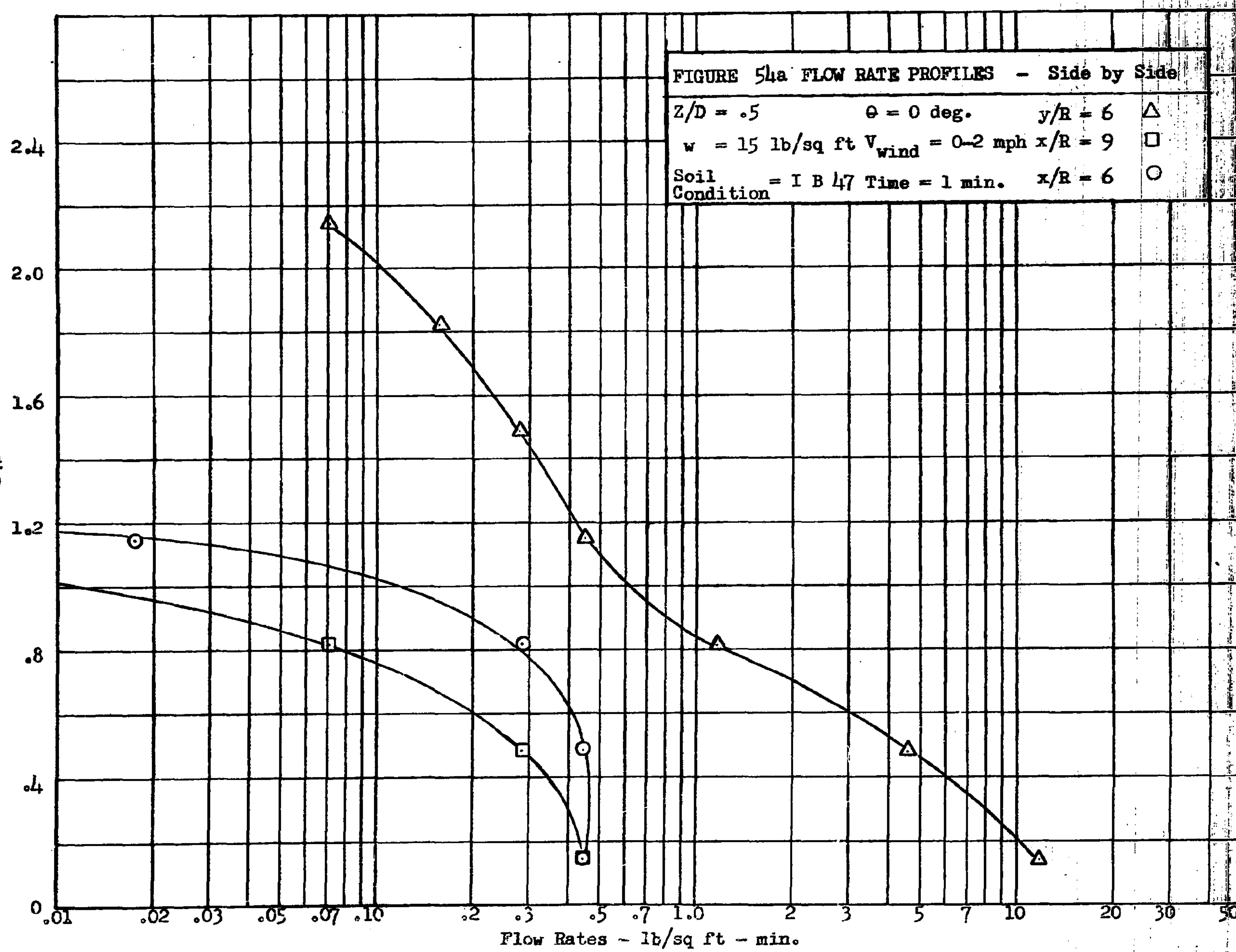


FIGURE 54a FLOW RATE PROFILES - Side by Side

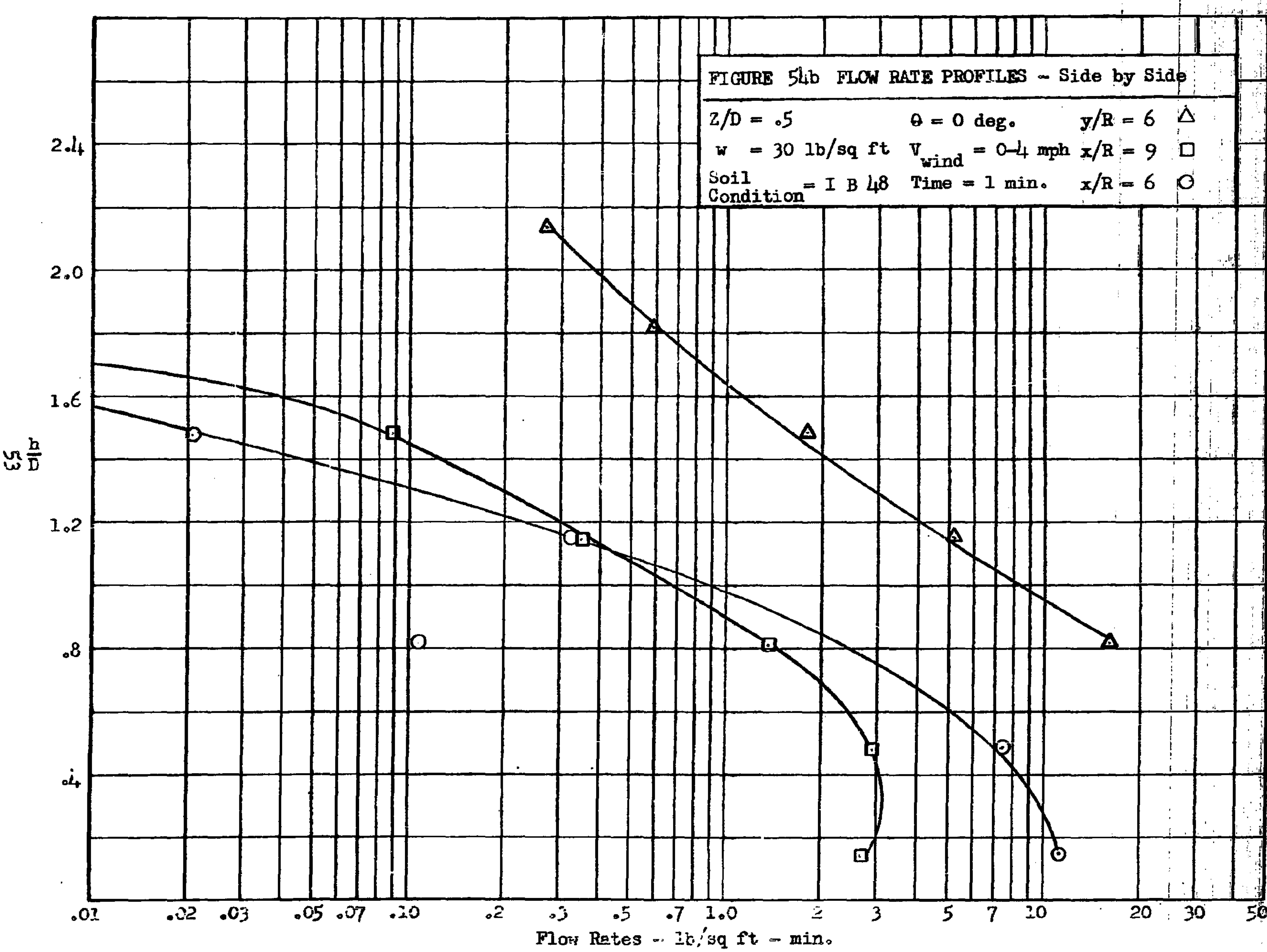


FIGURE 54b FLOW RATE PROFILES - Side by Side

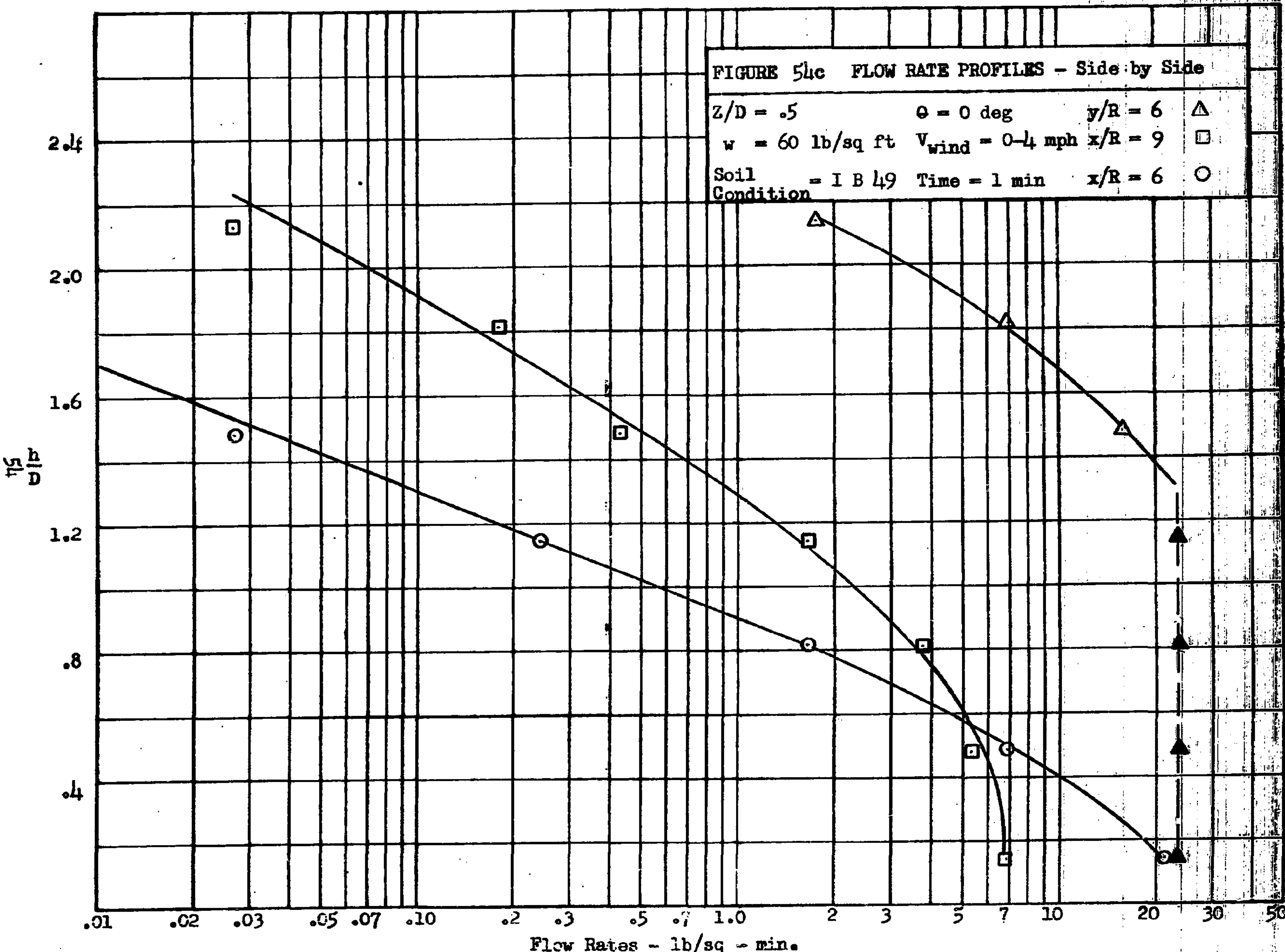


FIGURE 54c FLOW RATE PROFILES - Side by Side
Z/D = .5
θ = 0 deg
y/R = 6
w = 60 lb/sq ft
V wind = 0-4 mph
x/R = 9
Soil Condition = I B 49
Time = 1 min
x/R = 6
2.4
2.0
1.6
1.2
.8
.4
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq - min.

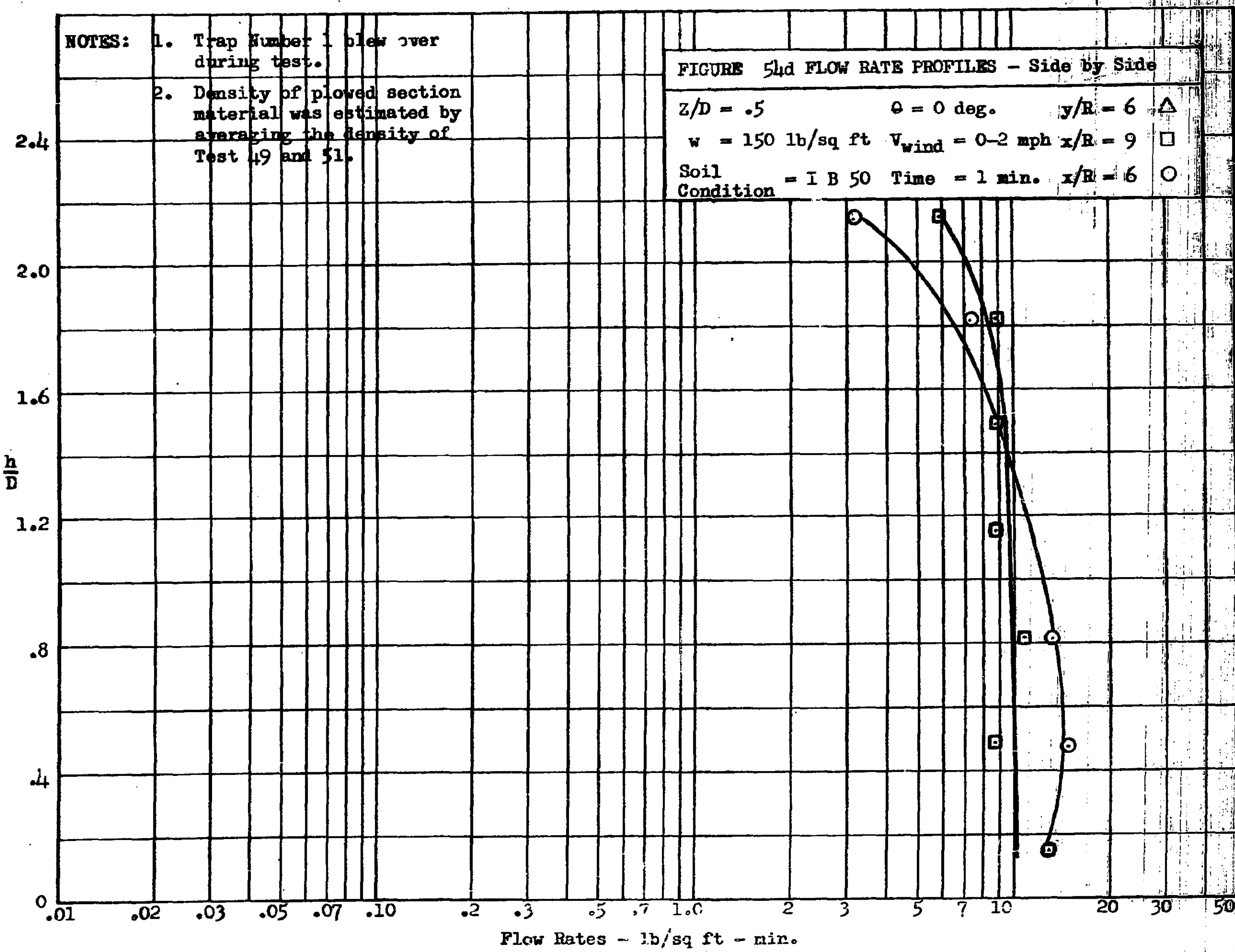


FIGURE 54d FLOW RATE PROFILES - Side by Side

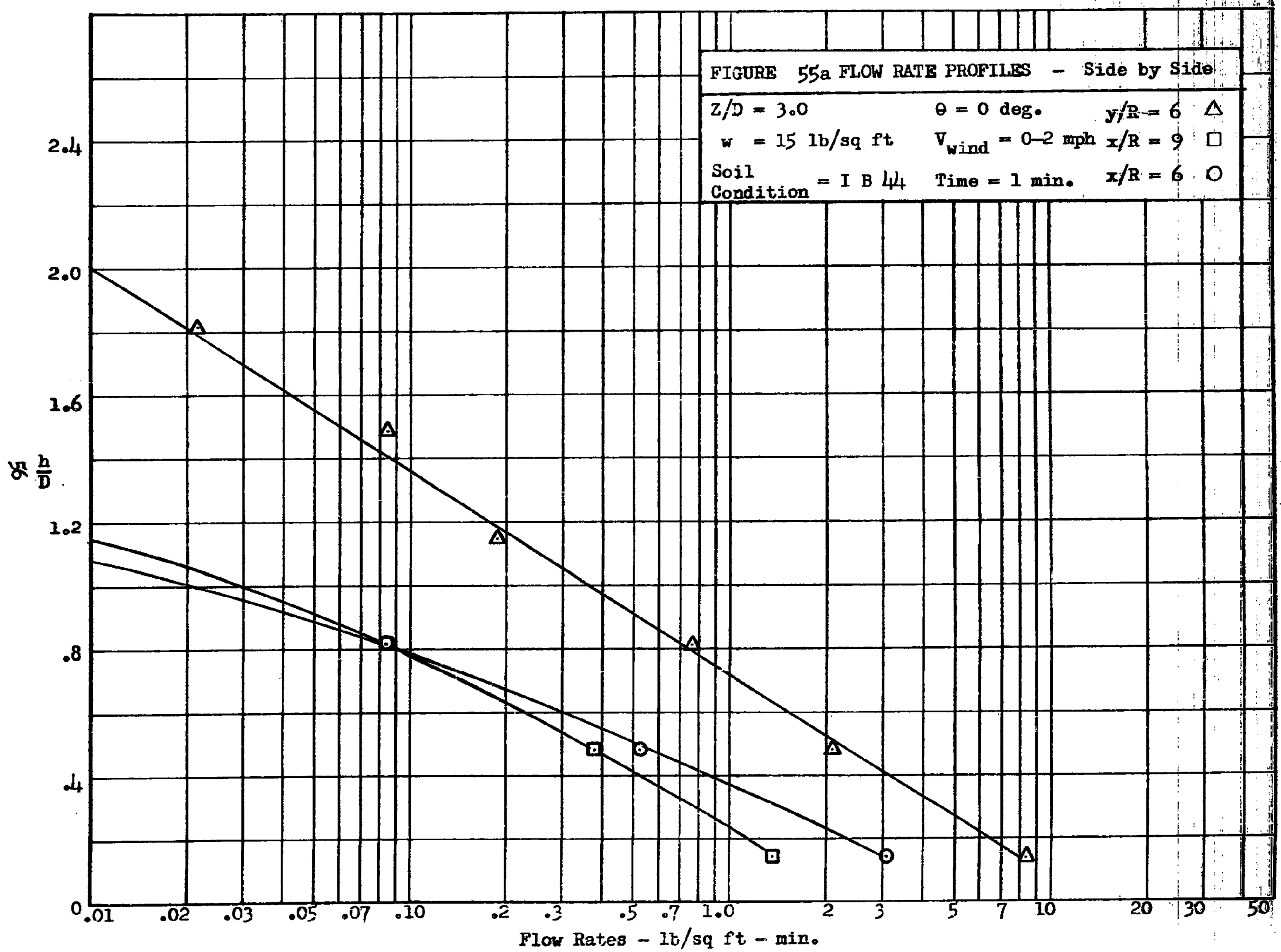


FIGURE 55a FLOW RATE PROFILES - Side by Side
Z/D = 3.0
θ = 0 deg.
y/R = 6
w = 15 lb/sq ft
V wind = 0-2 mph
x/R = 9
Soil Condition = I B 44
Time = 1 min.
x/R = 6
% h/D
0
.4
.8
1.2
1.6
2.0
2.4
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

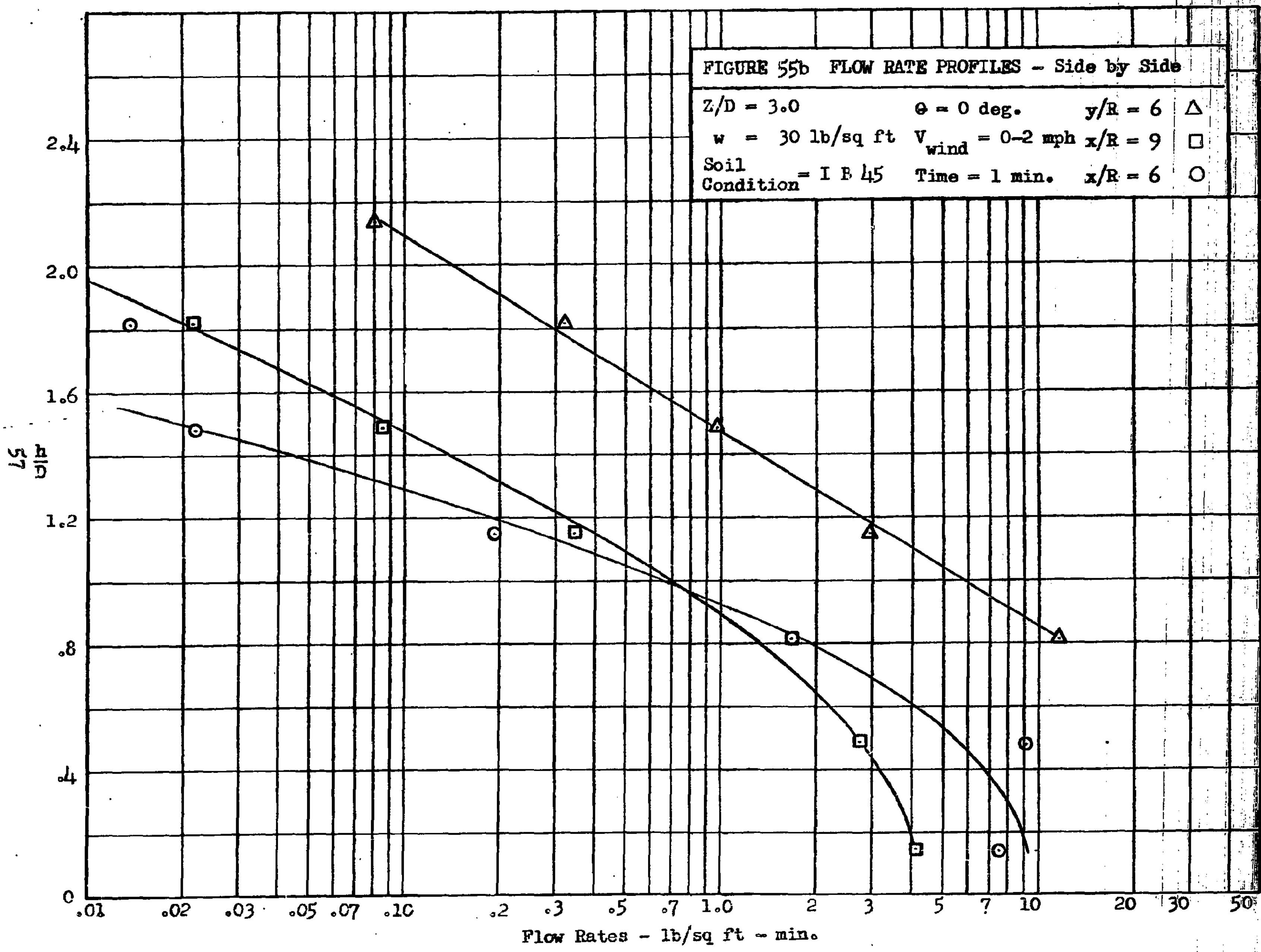


FIGURE 55b FLOW RATE PROFILES - Side by Side

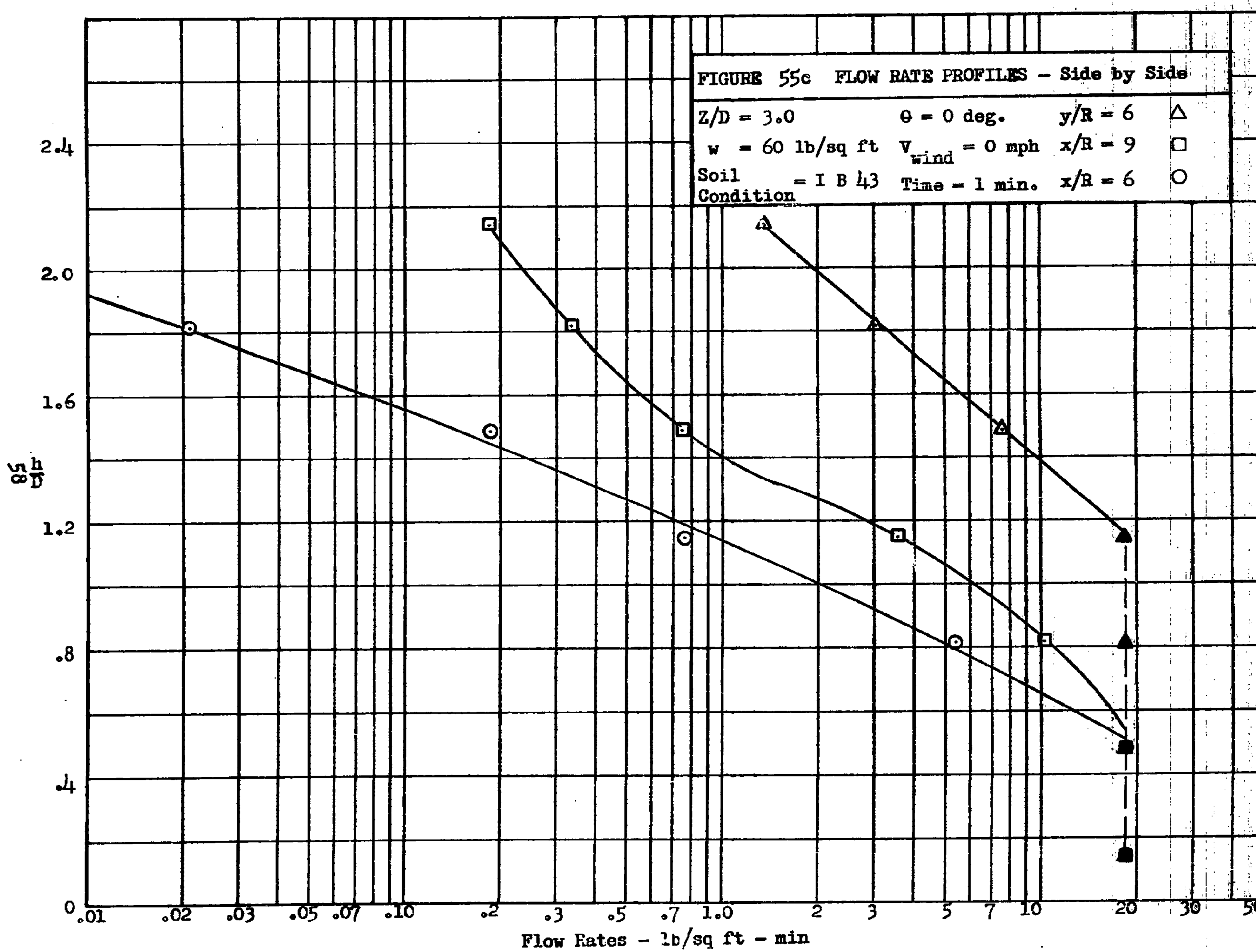


FIGURE 55c FLOW RATE PROFILES - Side by Side

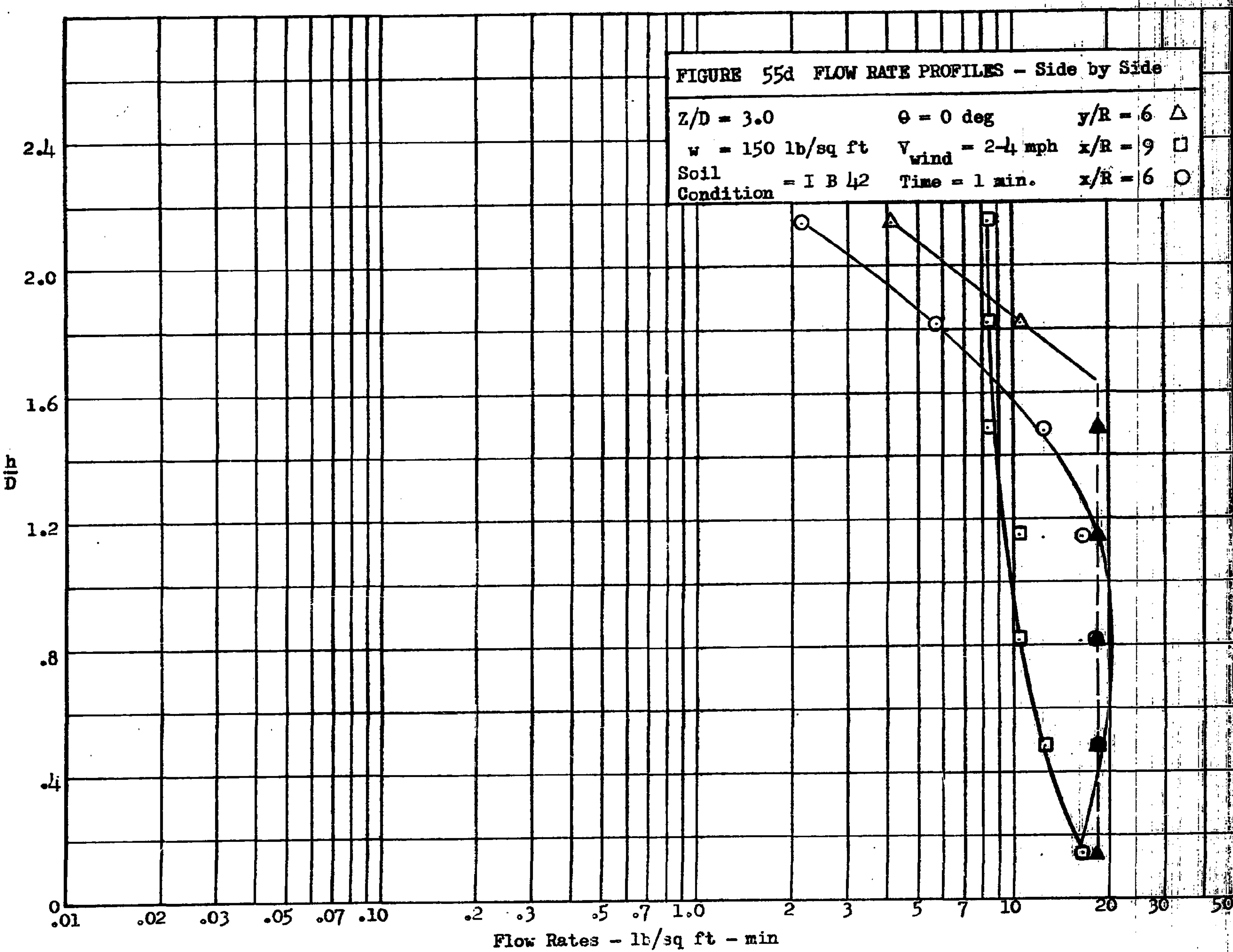


FIGURE 55d FLOW RATE PROFILES - Side by Side
Z/D = 3.0
w = 150 lb/sq ft
Soil Condition = I B 42
θ = 0 deg
V wind = 2-4 mph
Time = 1 min.
y/R = 6
x/R = 9
x/R = 6
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min

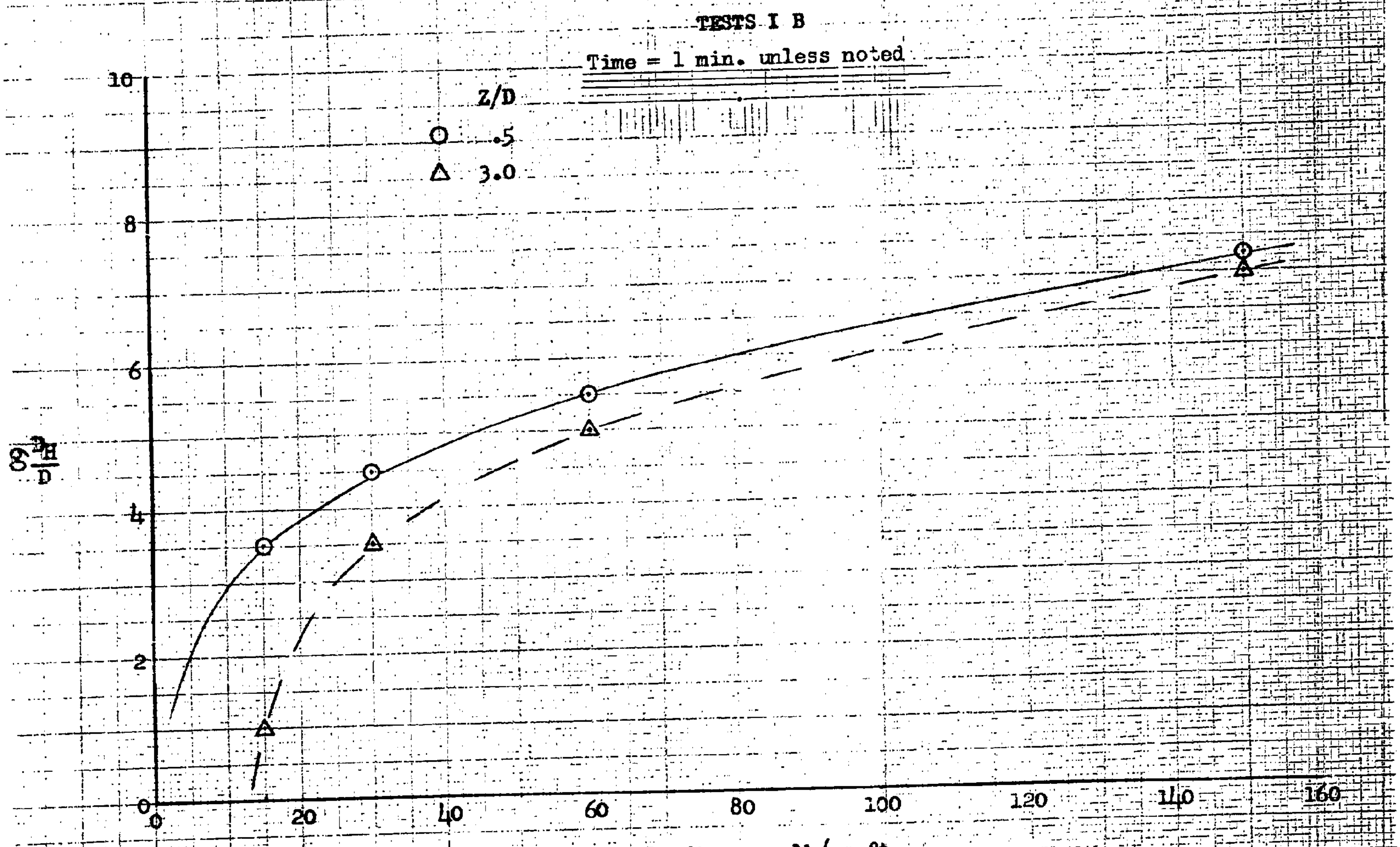


Figure 56 Relative Diameter of Eroded Section

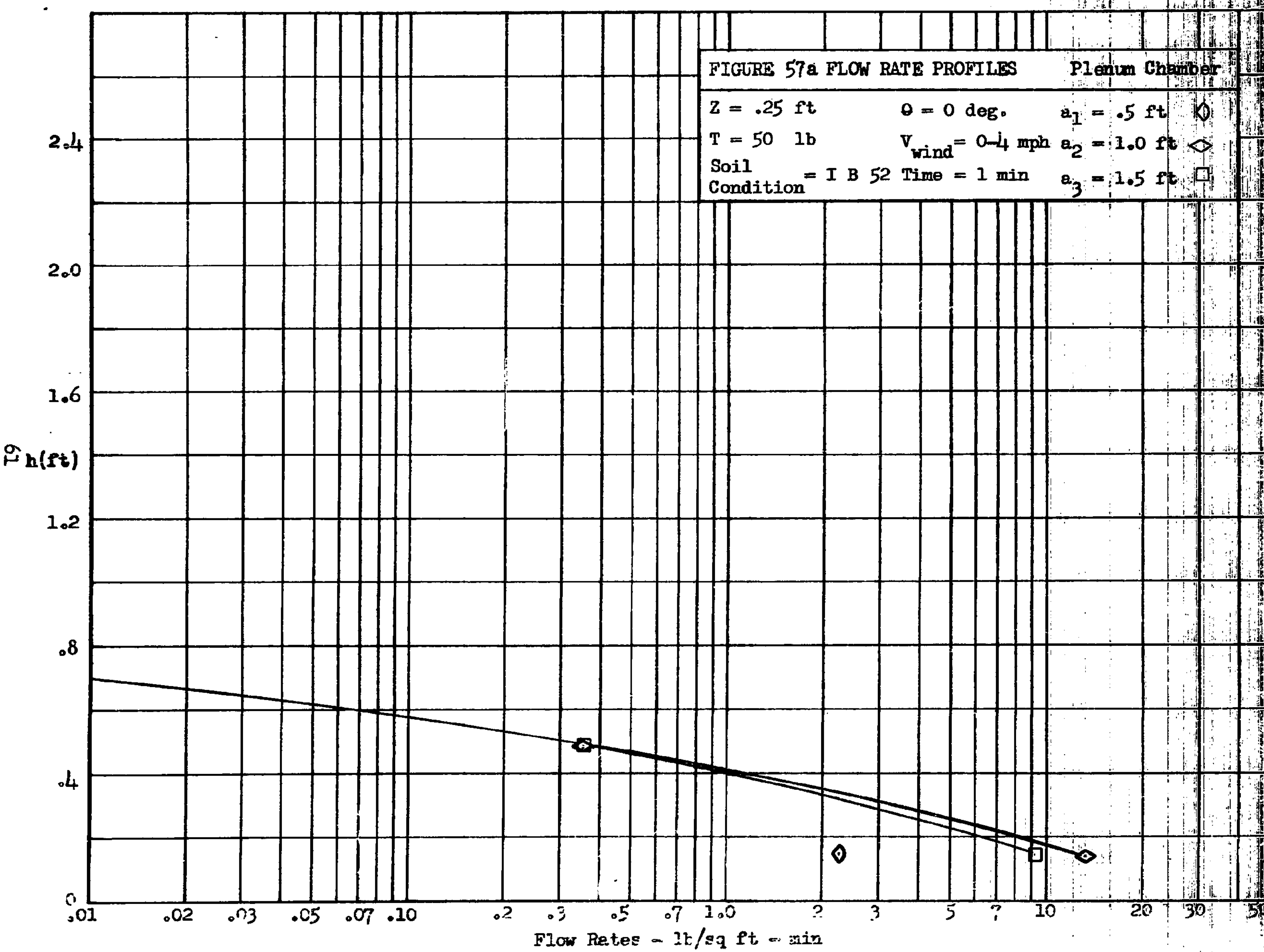


FIGURE 57a FLOW RATE PROFILES
Plenum Chamber
Z = .25 ft
T = 50 lb
Soil Condition = I B 52
Θ = 0 deg.
V wind = 0-4 mph
Time = 1 min
a1 = .5 ft
a2 = 1.0 ft
a3 = 1.5 ft
h(ft)
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min

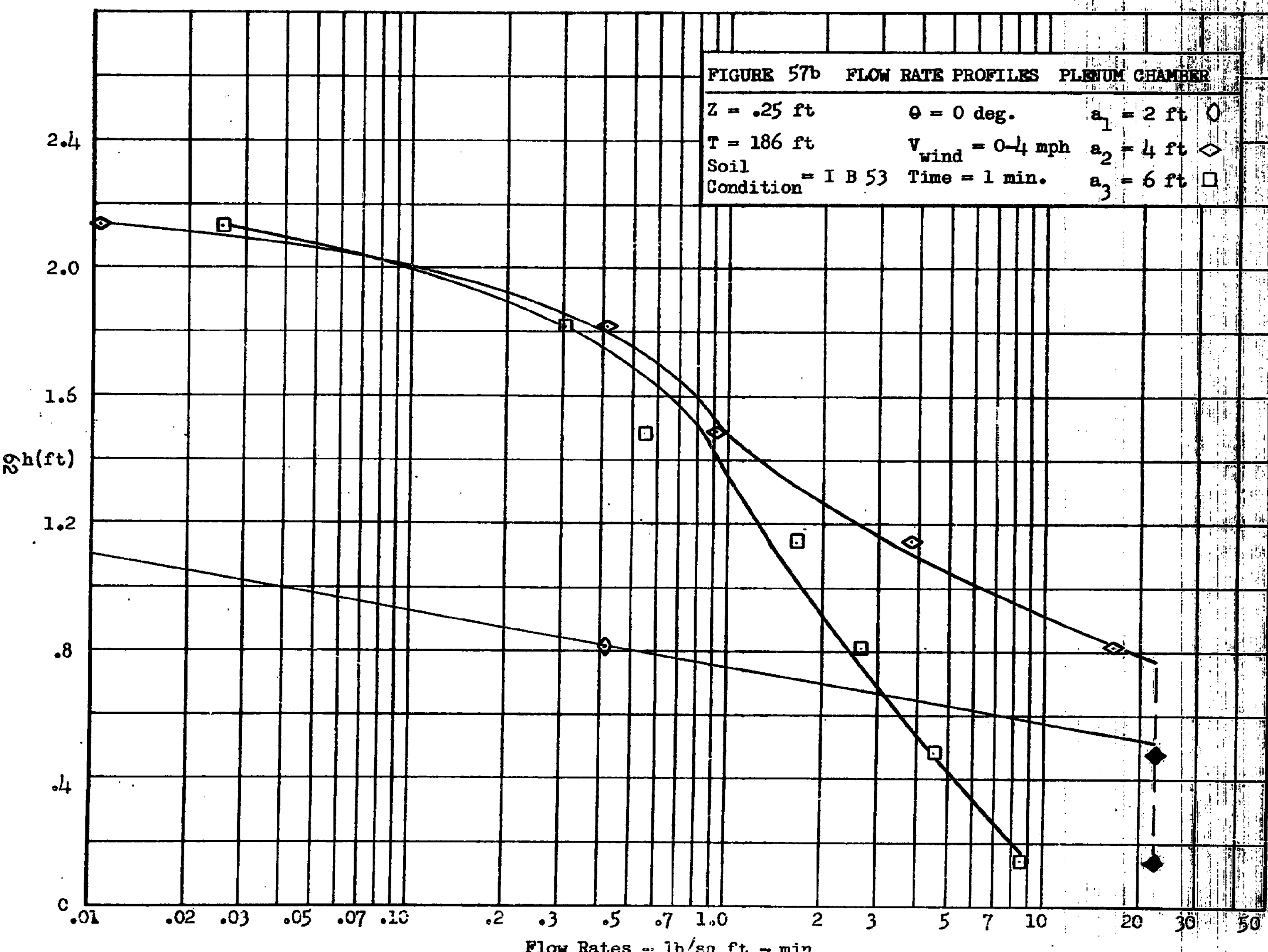


FIGURE 57b FLOW RATE PROFILES PLENUM CHAMBER

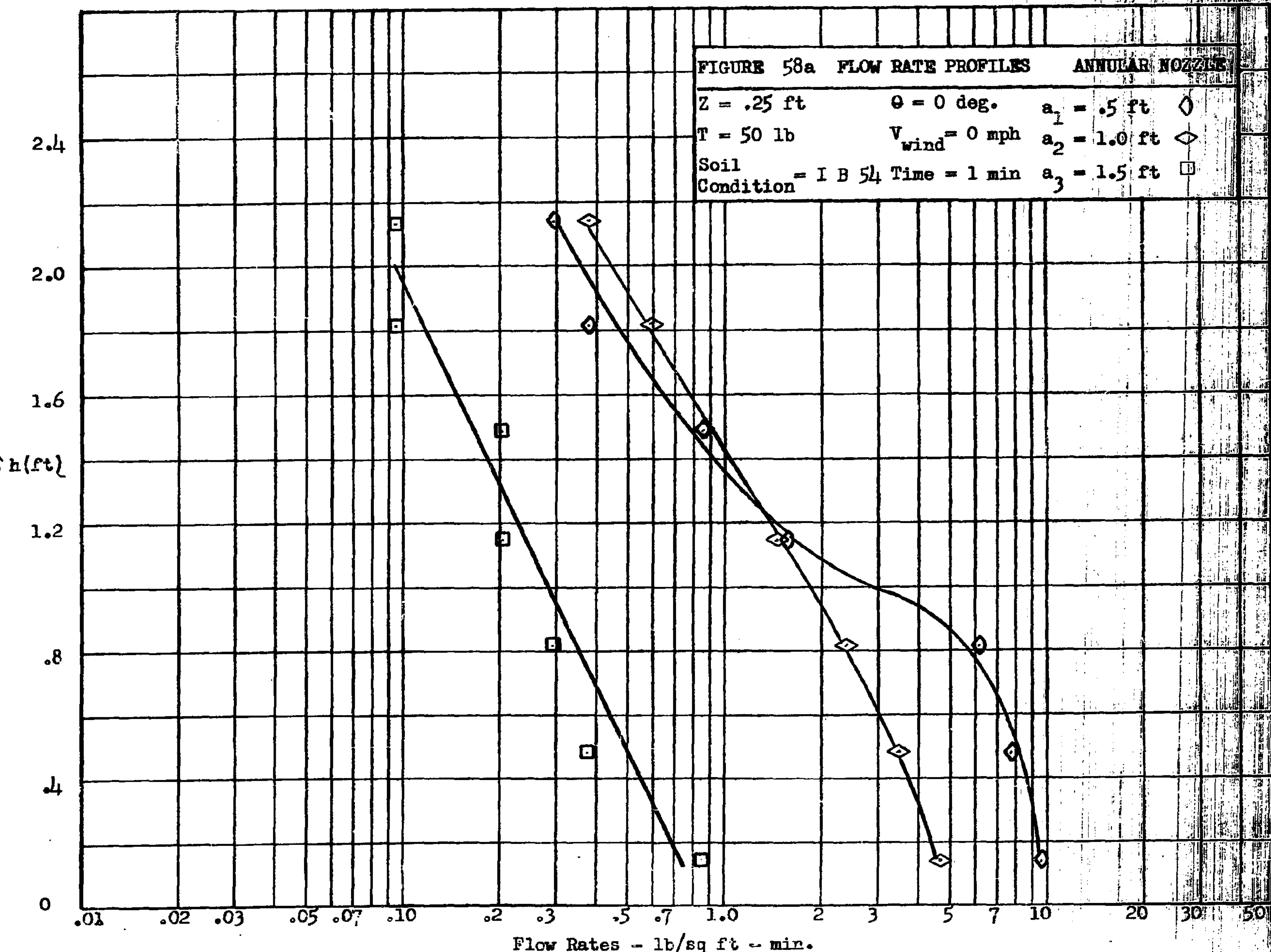


FIGURE 58a FLOW RATE PROFILES ANNULAR NOZZLE

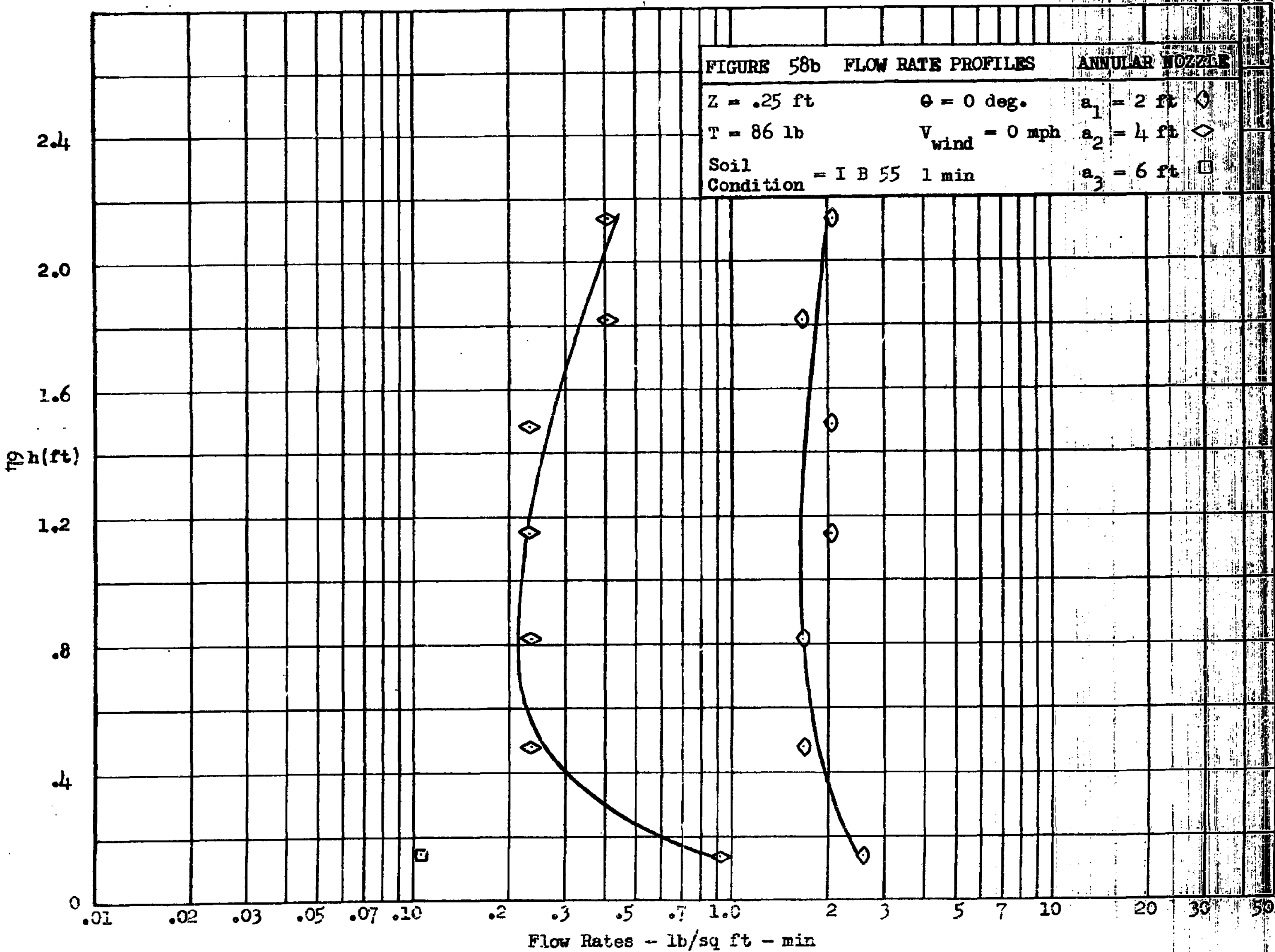


FIGURE 58b FLOW RATE PROFILES

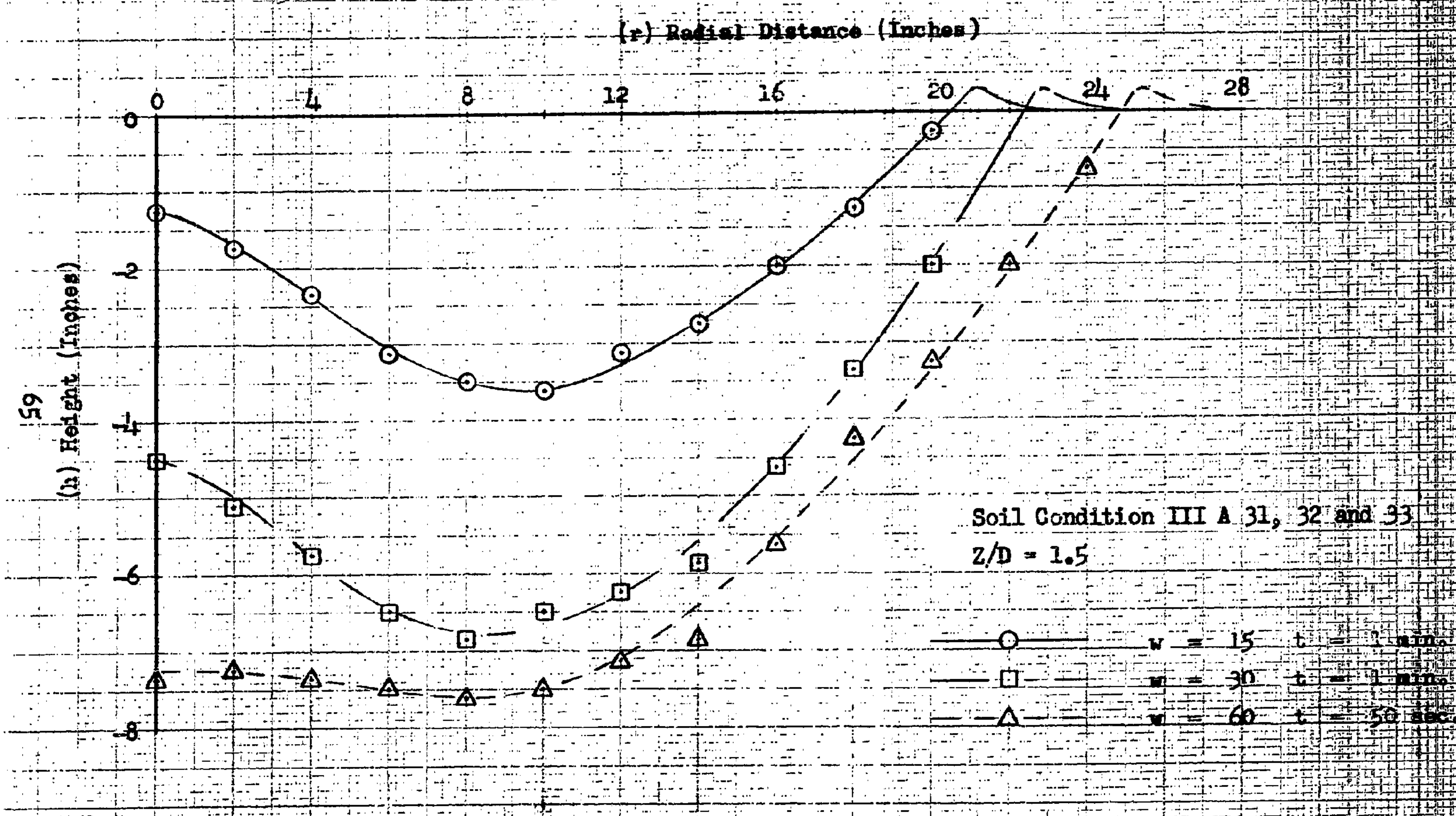


Figure 59 Profile of Eroded Sand

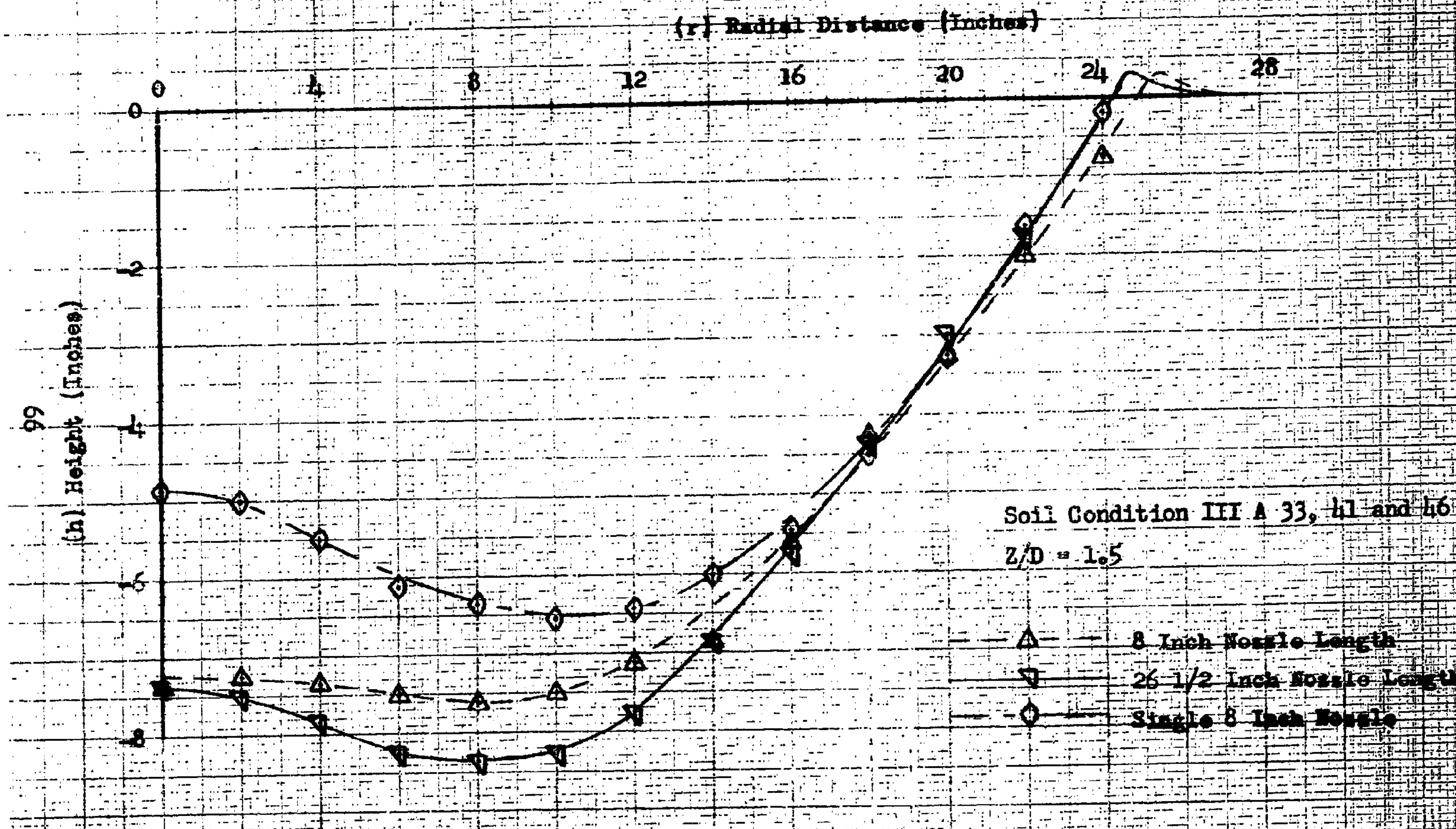


Figure 60 Profile of Eroded Sand

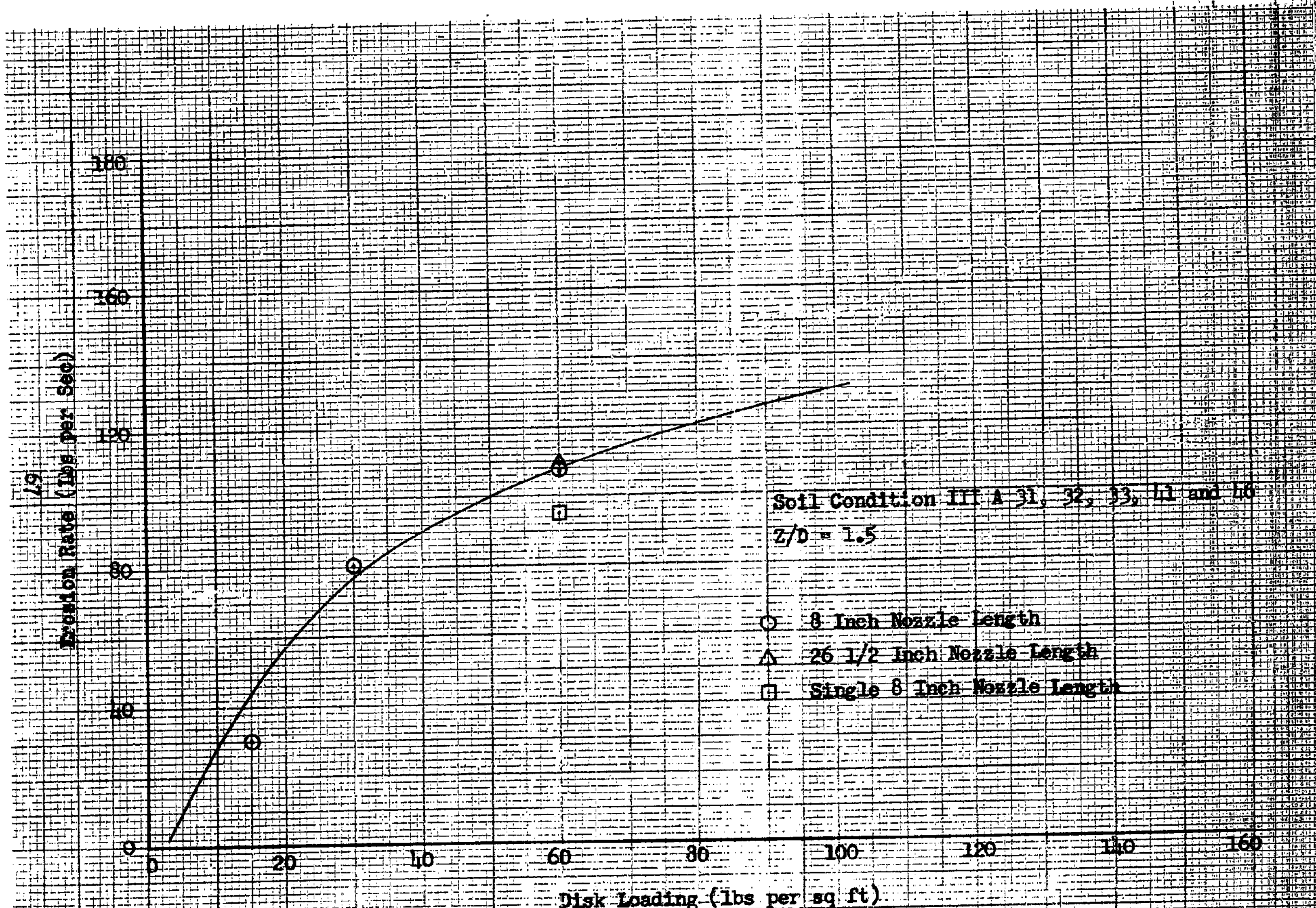


Figure 61 Erosion Rate Produced by a Single One-Foot Diameter Duct

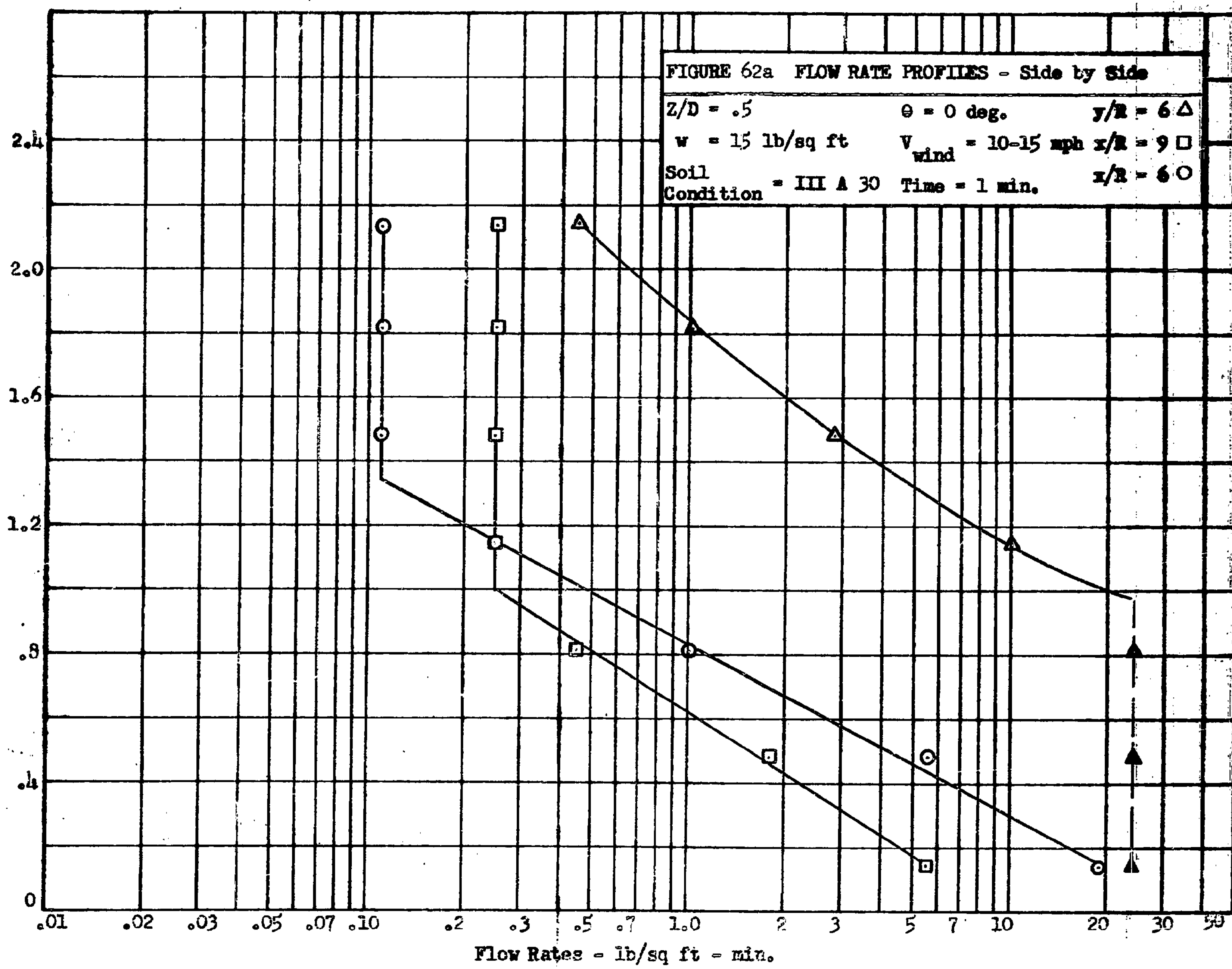


FIGURE 62a FLOW RATE PROFILES - Side by Side

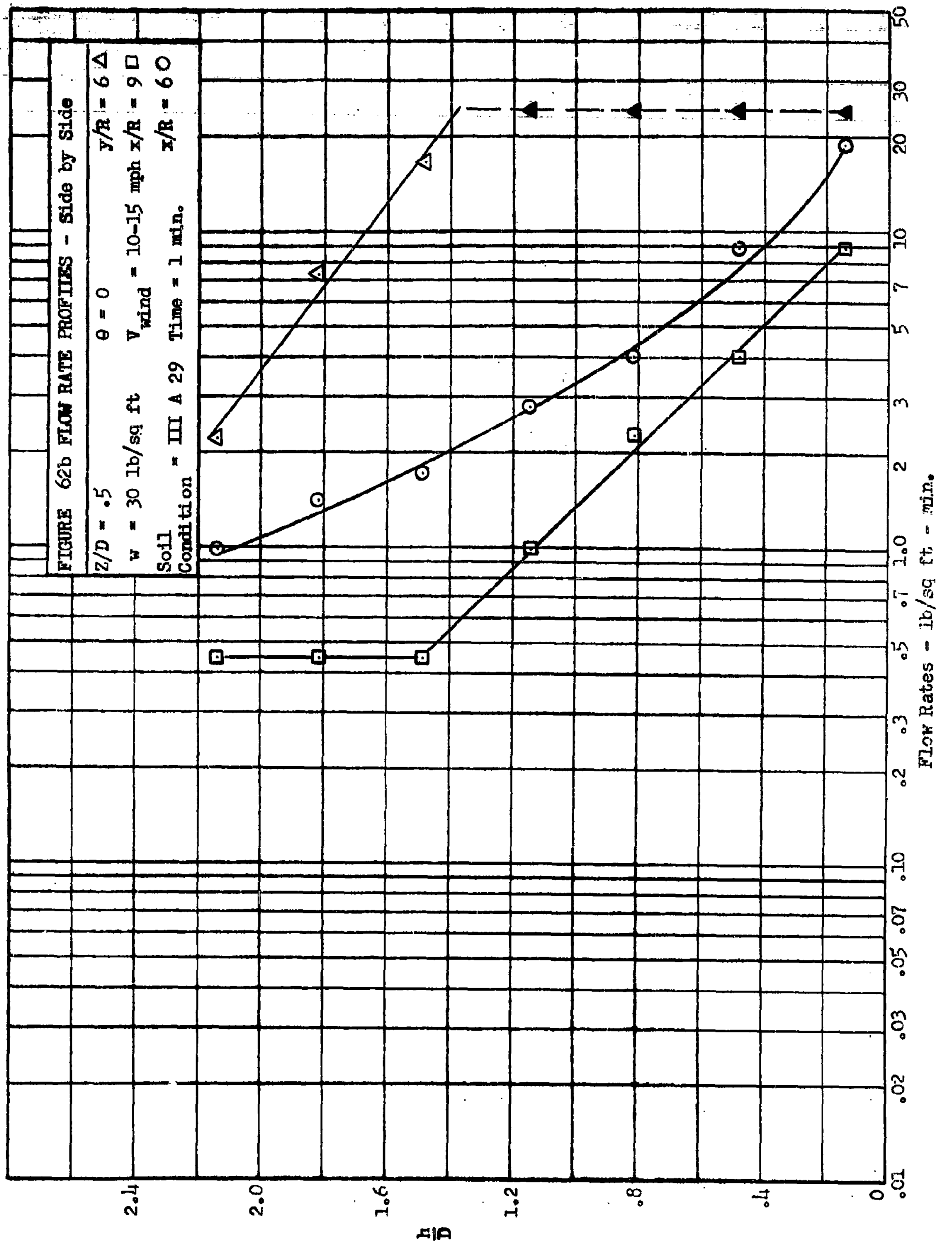


FIGURE 62b FLOW RATE PROFILES - Side by Side
Z/D = .5
θ = 0
y/R = 6 △
w = 30 lb/sq ft
V_wind = 10-15 mph
x/R = 9 □
Soil Condition = III A 29
Time = 1 min.
x/R = 6 ○
Flow Rates - lb/sq ft - min.
.01 .02 .03 .05 .07 .10 .2 .3 .5 .7 1.0 2 3 5 7 10 20 30 50
0 .4 .8 1.2 1.6 2.0 2.4
h/D

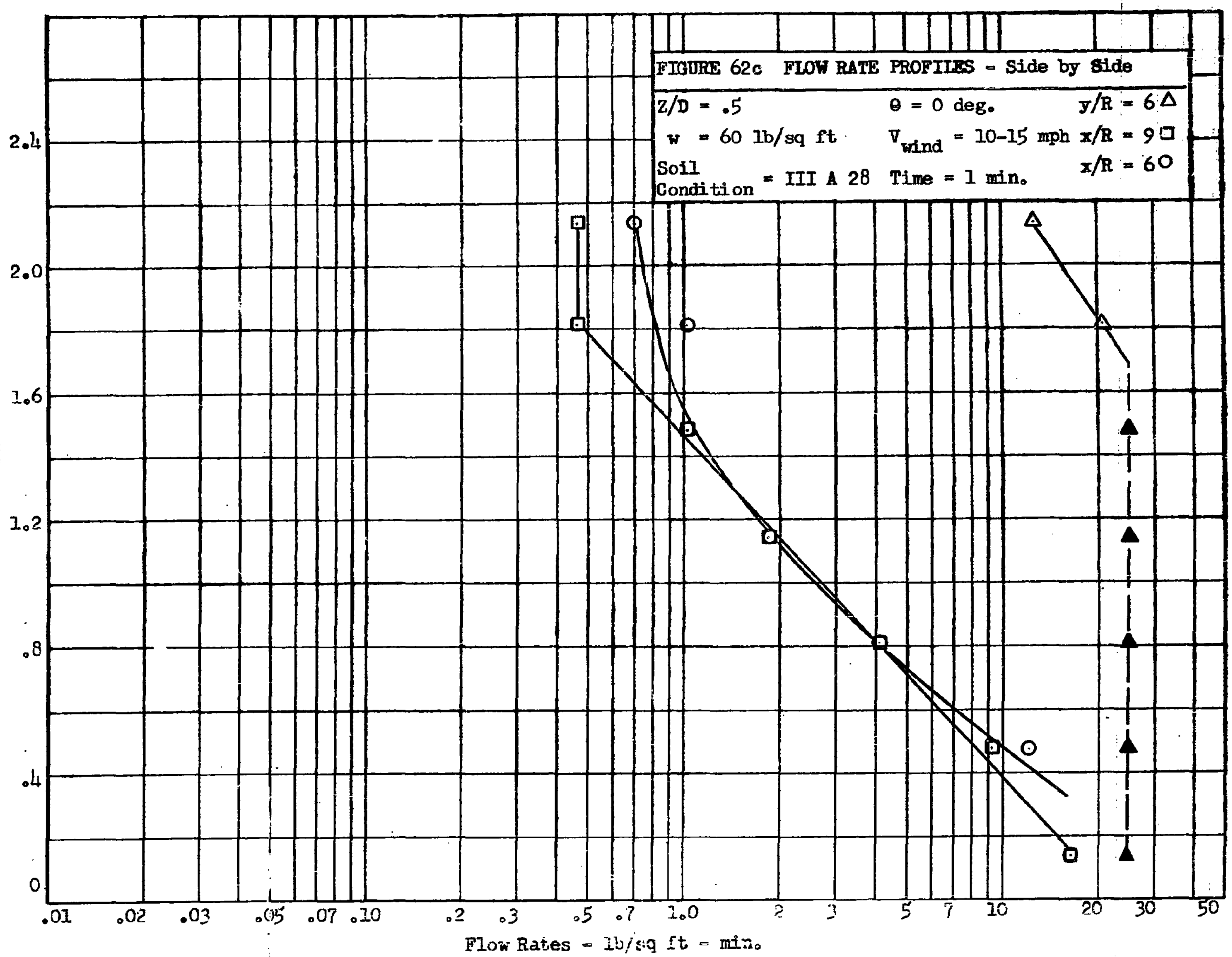


FIGURE 62c FLOW RATE PROFILES - Side by Side

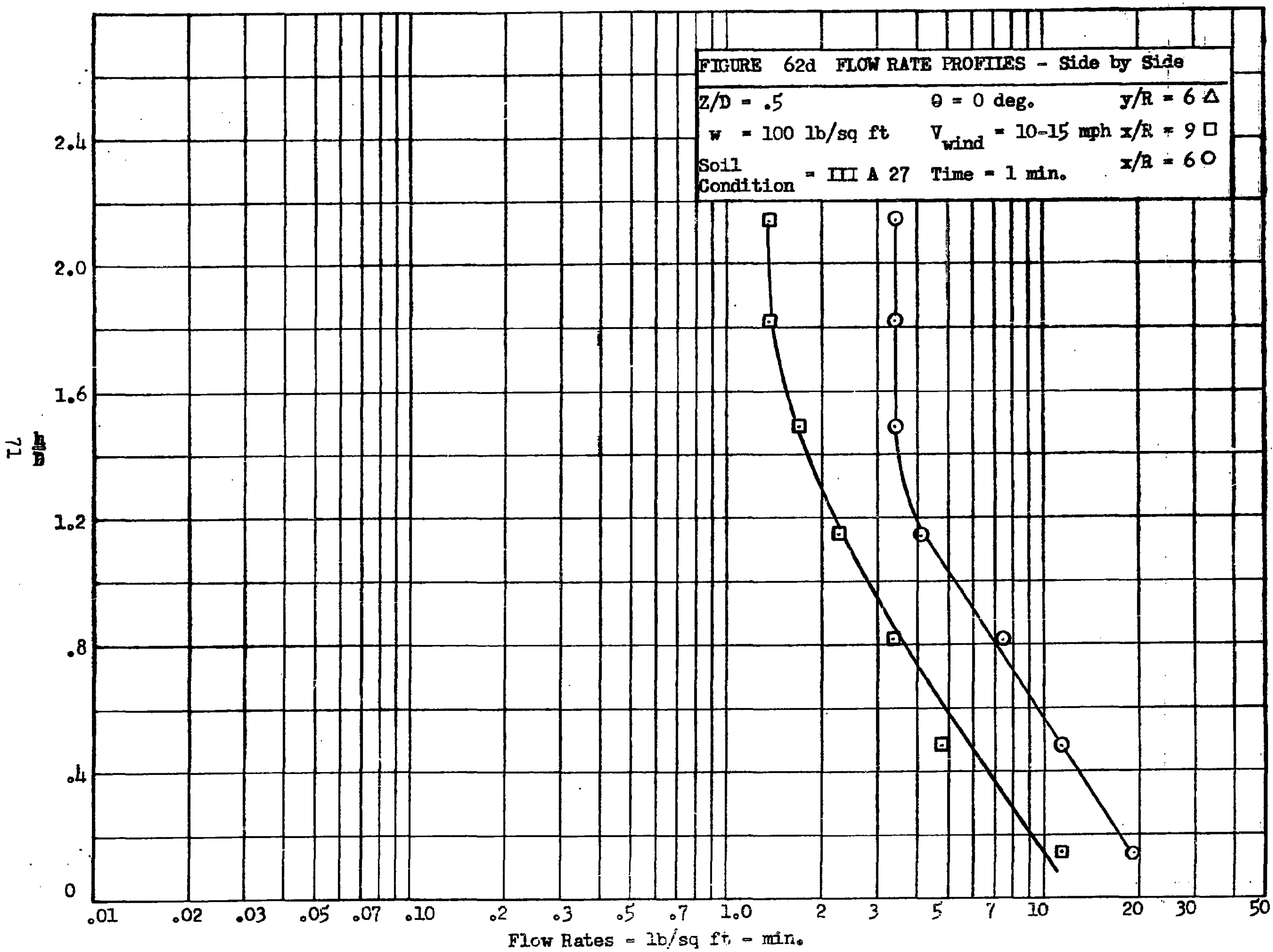


FIGURE 62d FLOW RATE PROFILES - Side by Side
Z/D = .5
θ = 0 deg.
y/R = 6 △
w = 100 lb/sq ft
V_{wind} = 10-15 mph
x/R = 9 □
Soil Condition = III A 27
Time = 1 min.
x/R = 6 ○
2.4
2.0
1.6
1.2
.8
.4
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

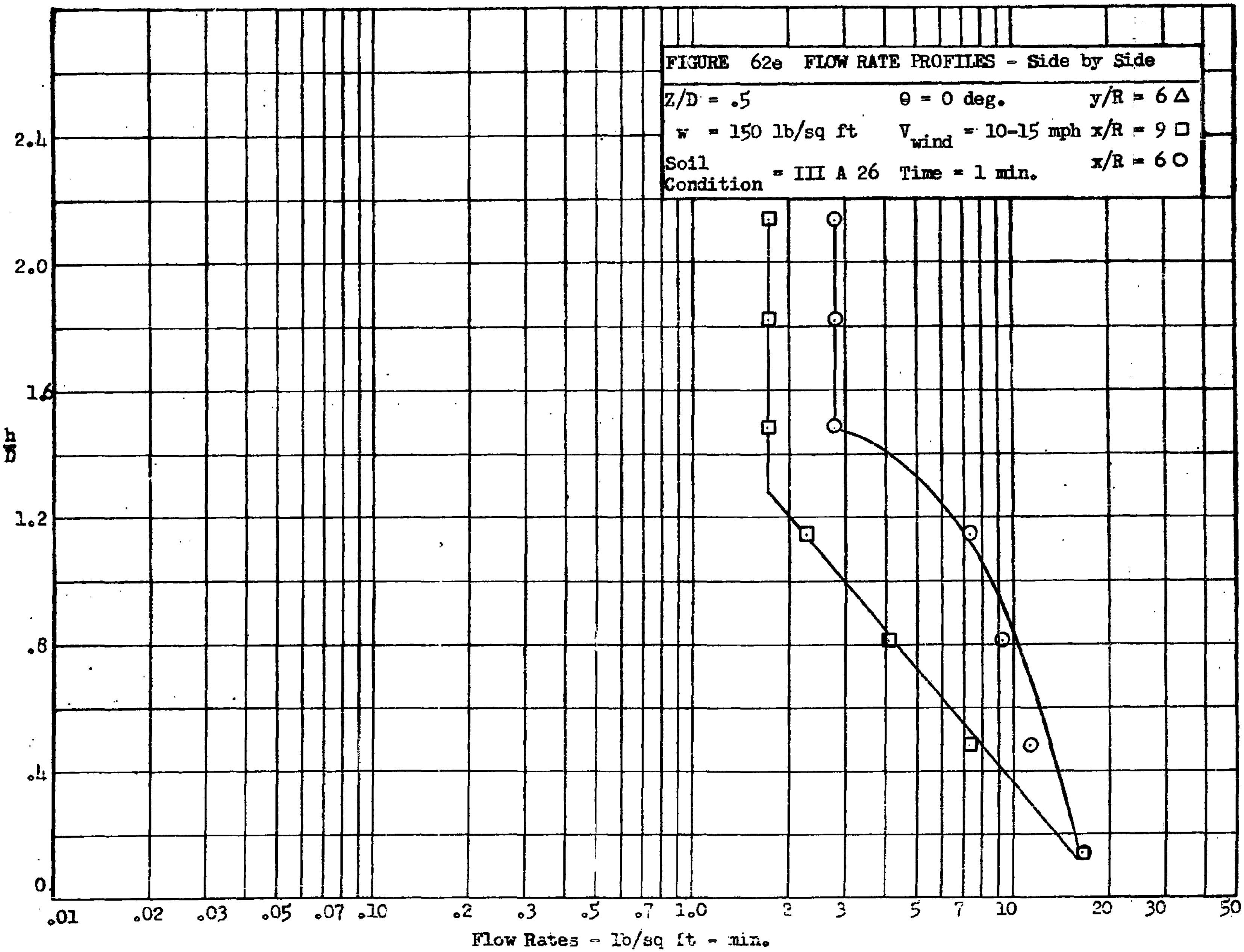


FIGURE 62e FLOW RATE PROFILES - Side by Side
Z/D = .5
θ = 0 deg.
y/R = 6 △
w = 150 lb/sq ft
V wind = 10-15 mph
x/R = 9 □
Soil Condition = III A 26
Time = 1 min.
x/R = 6 ○
2.4
2.0
1.6
1.2
.8
.4
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

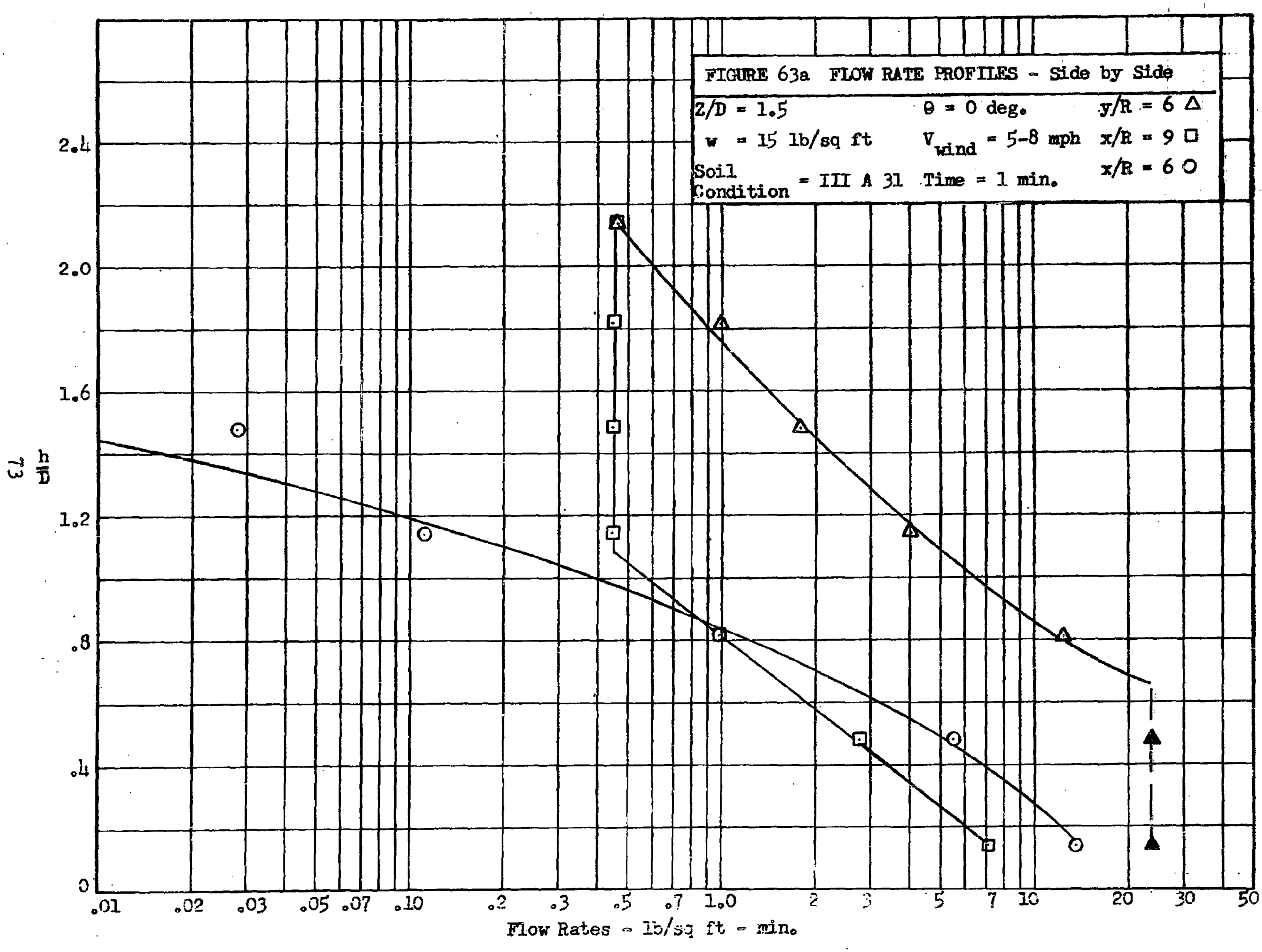


FIGURE 63a FLOW RATE PROFILES - Side by Side
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 15 lb/sq ft
V wind = 5-8 mph
x/R = 9 □
x/R = 6 ○
Soil Condition = III A 31
Time = 1 min.
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

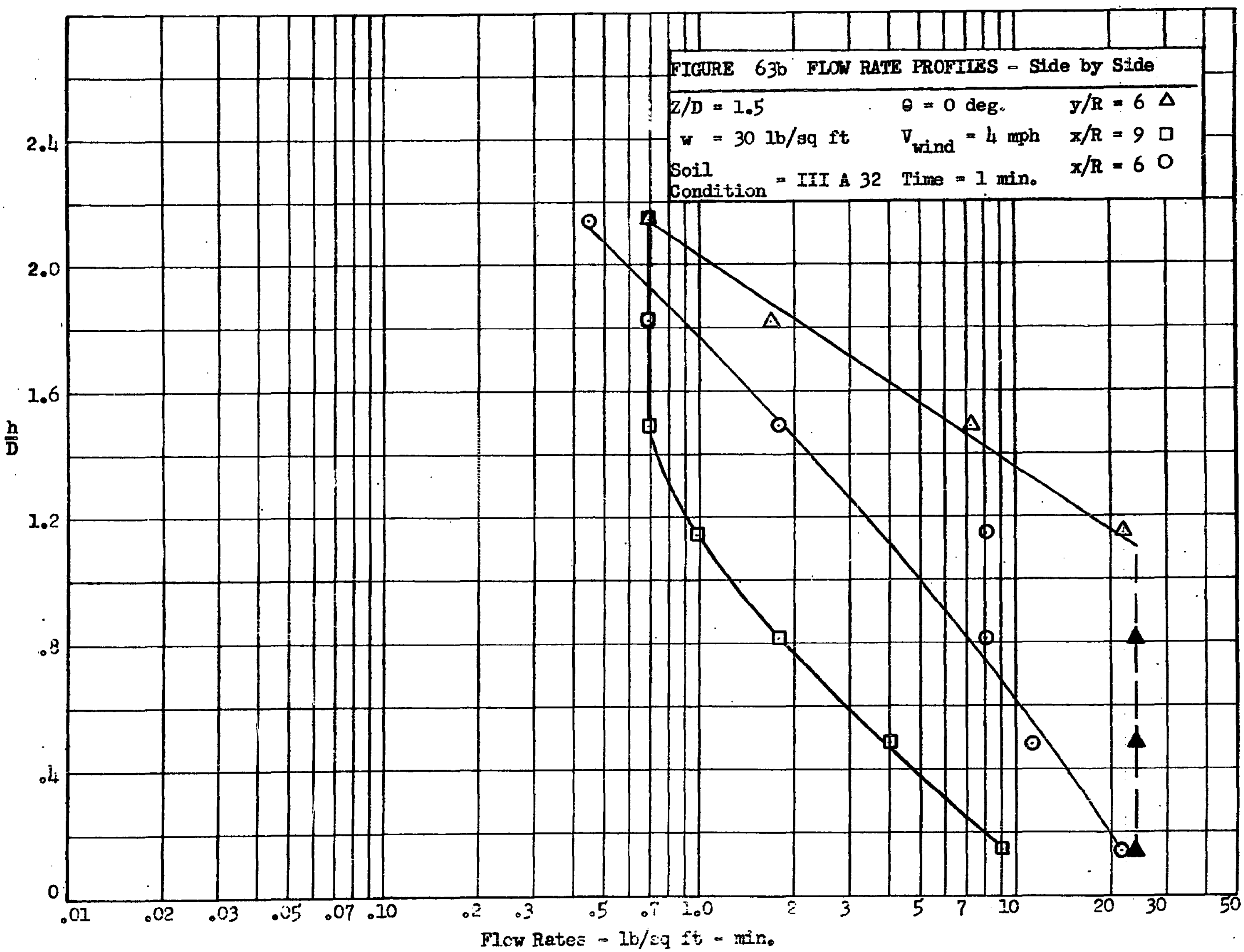


FIGURE 63b FLOW RATE PROFILES - Side by Side
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 30 lb/sq ft
V wind = 4 mph
x/R = 9 □
Soil Condition = III A 32
Time = 1 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

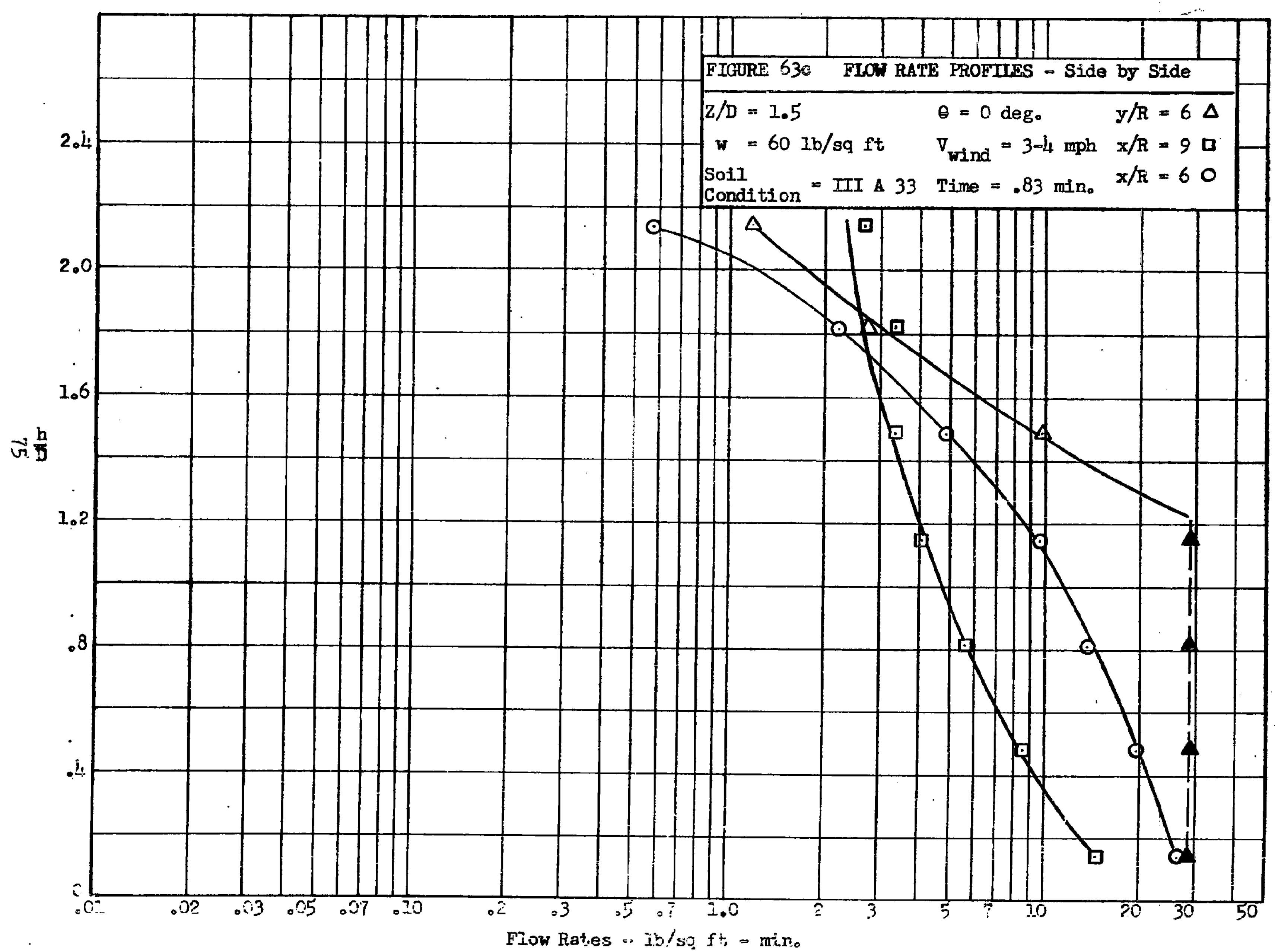


FIGURE 63c FLOW RATE PROFILES - Side by Side
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 60 lb/sq ft
V wind = 3-4 mph
x/R = 9 □
Soil Condition = III A 33
Time = .83 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

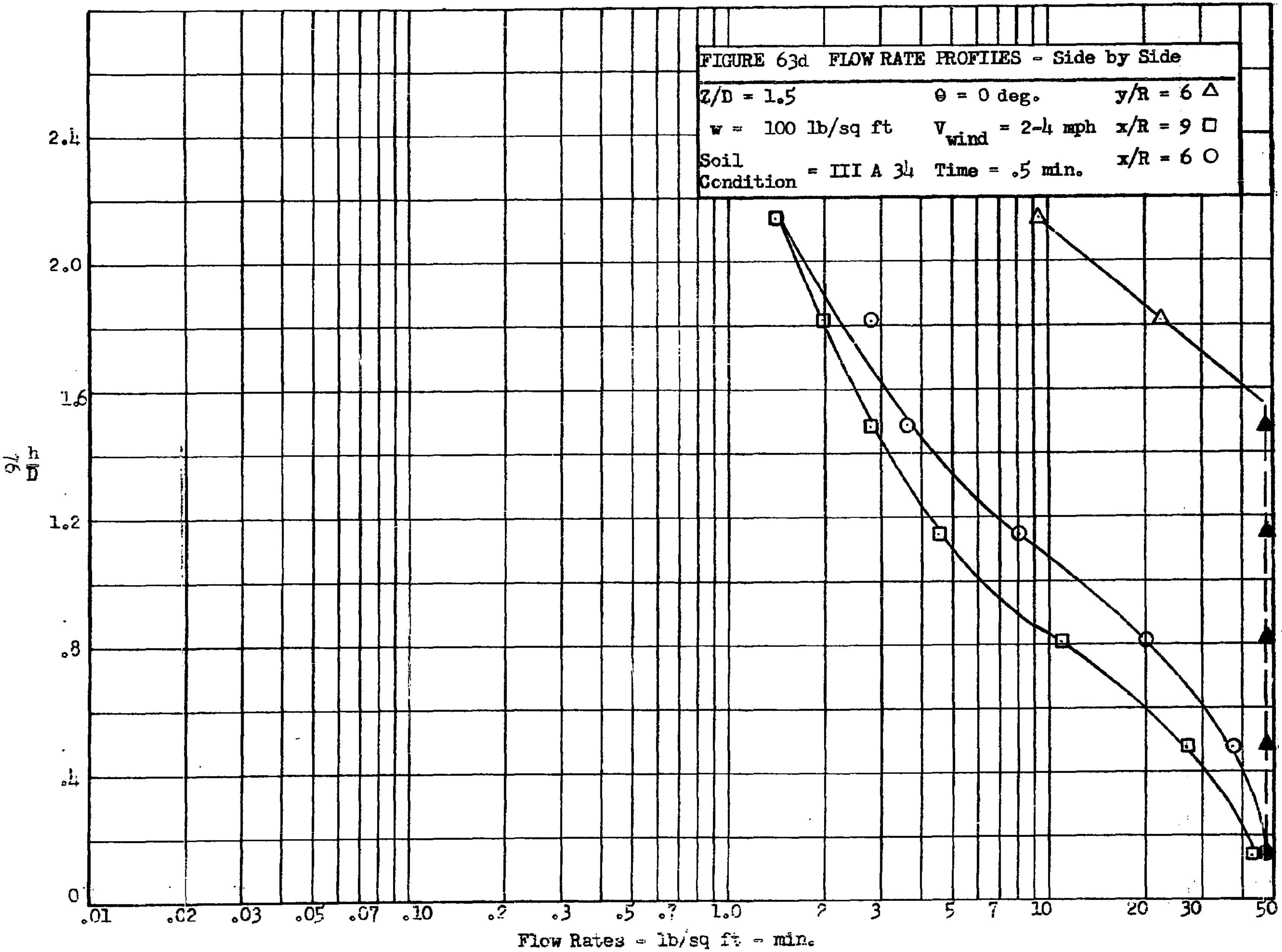


FIGURE 63d FLOW RATE PROFILES - Side by Side
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 100 lb/sq ft
V wind = 2-4 mph
x/R = 9 □
Soil Condition = III A 34
Time = .5 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

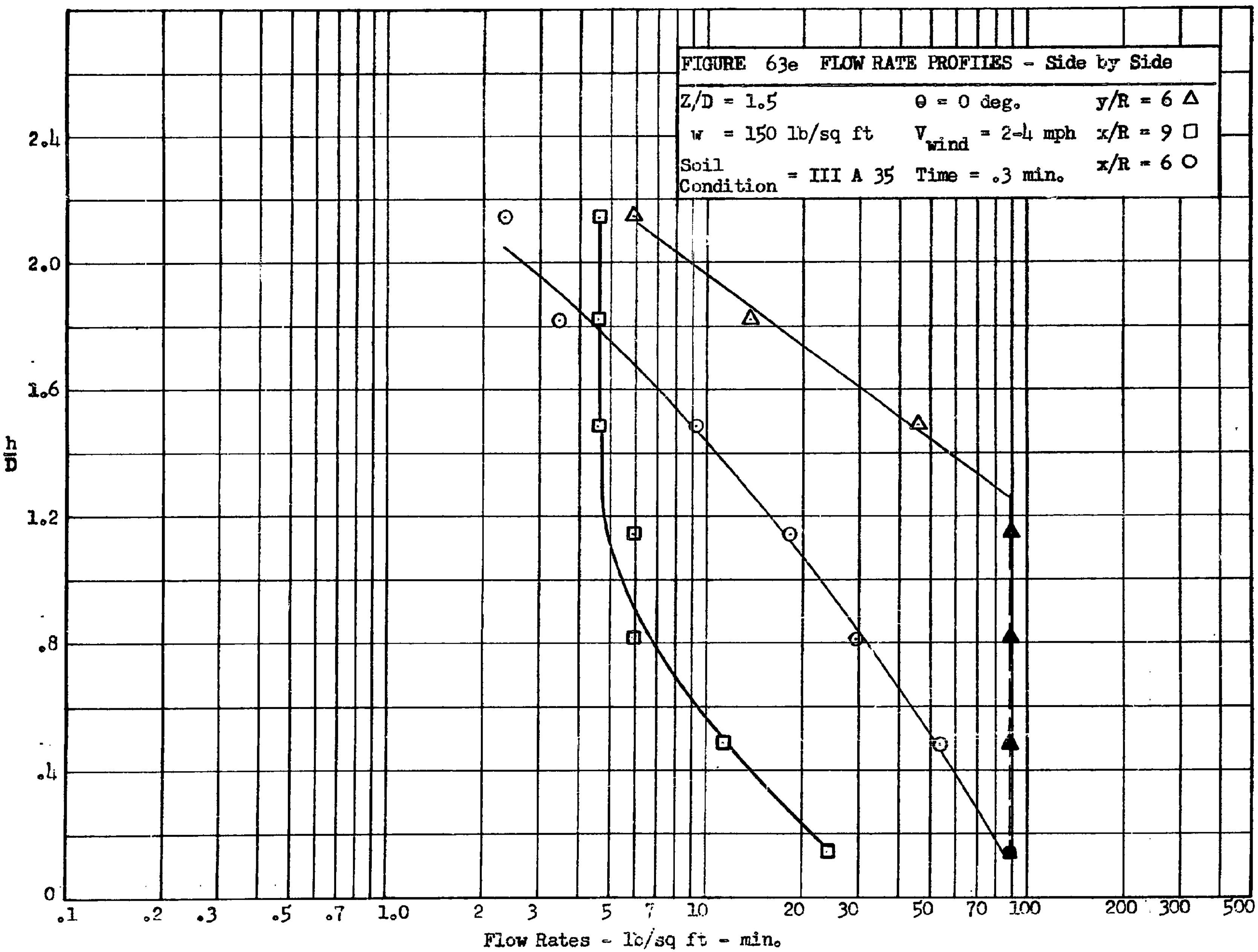


FIGURE 63e FLOW RATE PROFILES - Side by Side
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 150 lb/sq ft
V wind = 2-4 mph
x/R = 9 □
Soil Condition = III A 35
Time = .3 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.1
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
70
100
200
300
500
Flow Rates - lb/sq ft - min.

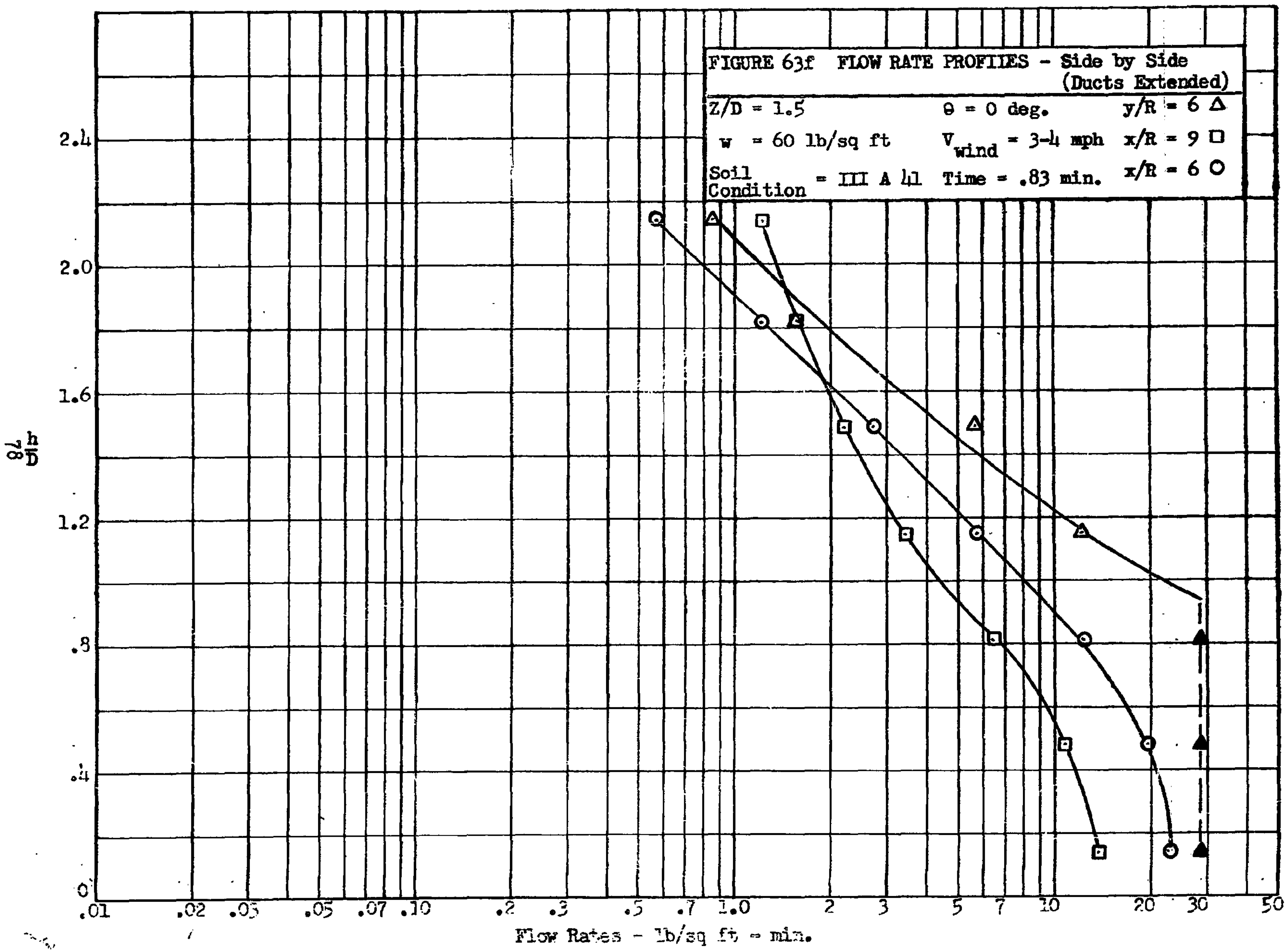


FIGURE 63f FLOW RATE PROFILES - Side by Side
(Ducts Extended)
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 60 lb/sq ft
V wind = 3-4 mph
x/R = 9 □
Soil Condition = III A 41
Time = .83 min.
x/R = 6 ○
2.4
2.0
1.6
1.2
.8
.4
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

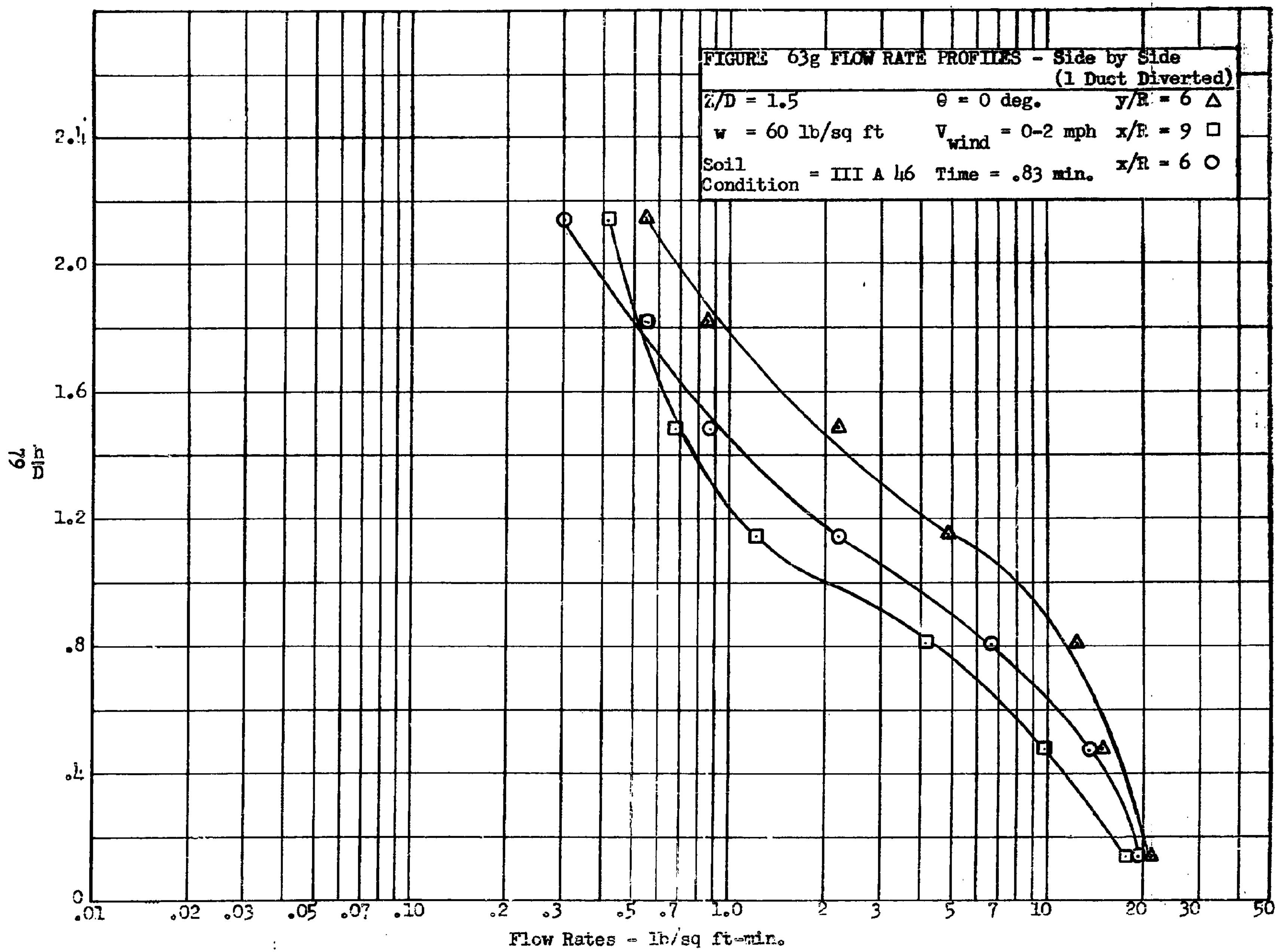


FIGURE 63g FLOW RATE PROFILES - Side by Side (1 Duct Diverted)
Z/D = 1.5
θ = 0 deg.
y/R = 6 △
w = 60 lb/sq ft
V wind = 0-2 mph
x/R = 9 □
Soil Condition = III A 46
Time = .83 min.
x/R = 6 ○
2.4
2.0
1.6
1.2
.8
.4
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft-min.

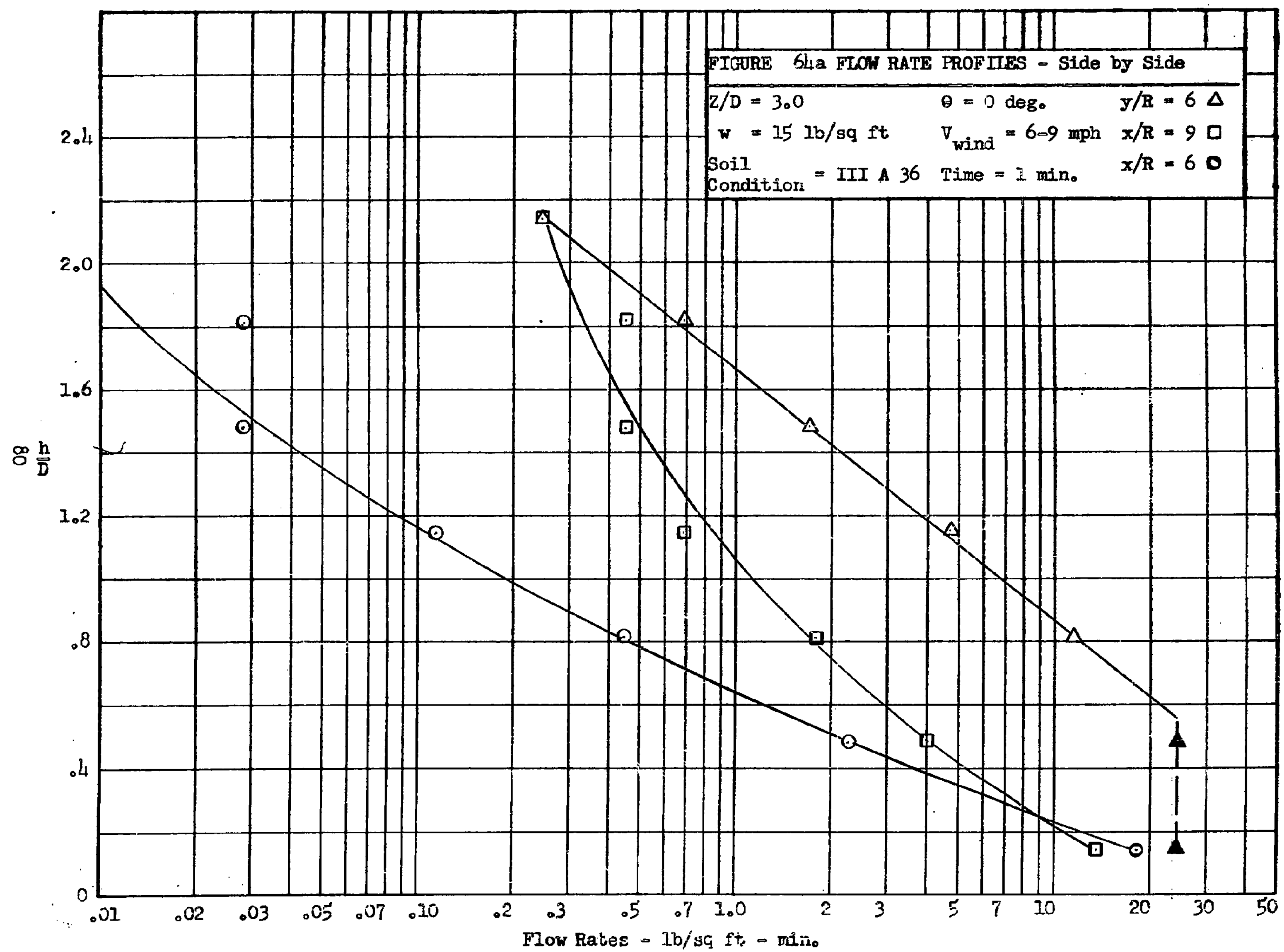


FIGURE 64a FLOW RATE PROFILES - Side by Side
Z/D = 3.0
w = 15 lb/sq ft
Soil Condition = III A 36
θ = 0 deg.
V_{wind} = 6-9 mph
Time = 1 min.
y/R = 6
x/R = 9
x/R = 6
$\frac{h}{D}$
0
.4
.8
1.2
1.6
2.0
2.4
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

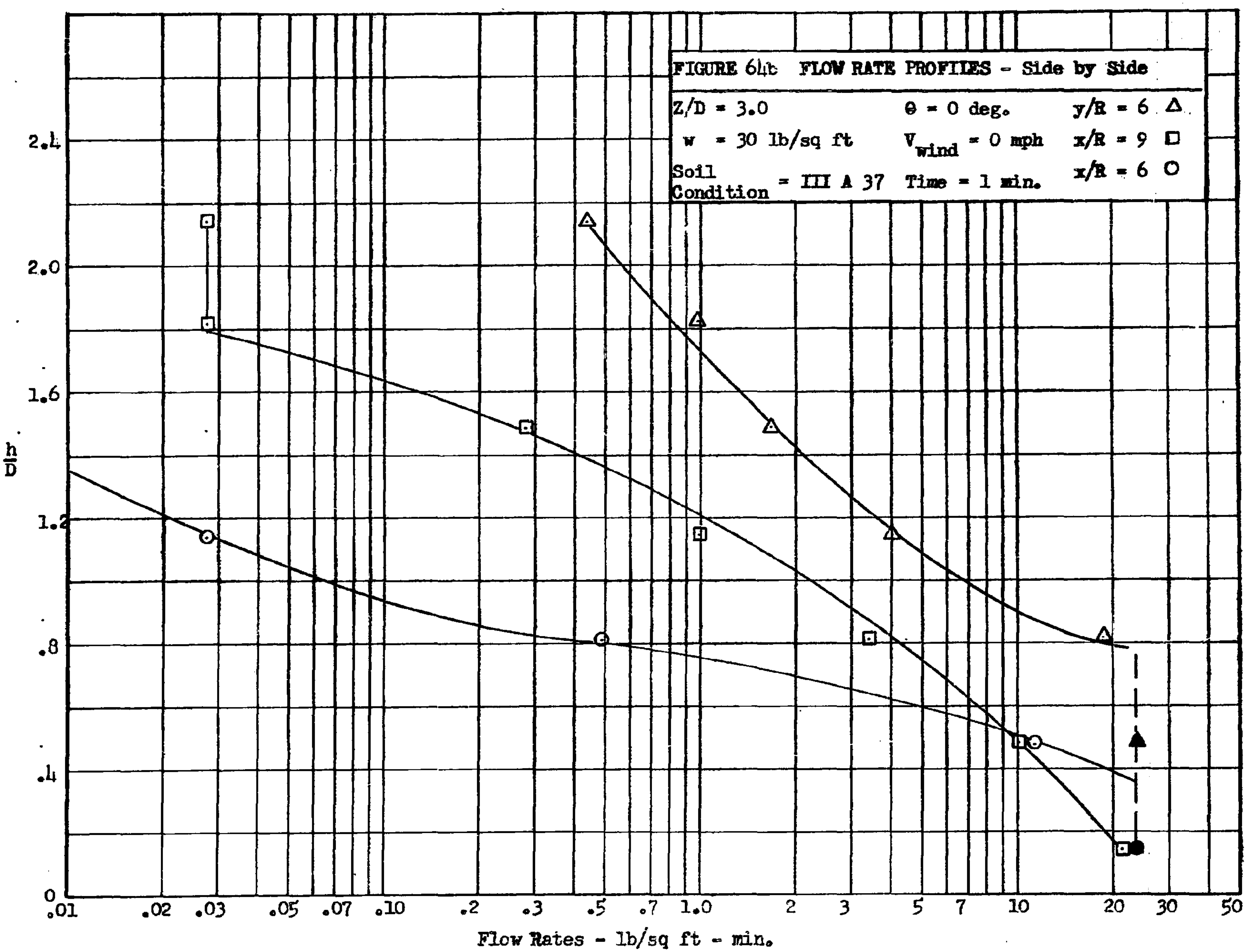


FIGURE 64b FLOW RATE PROFILES - Side by Side
Z/D = 3.0
θ = 0 deg.
y/R = 6 △
w = 30 lb/sq ft
V wind = 0 mph
x/R = 9 □
Soil Condition = III A 37
Time = 1 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

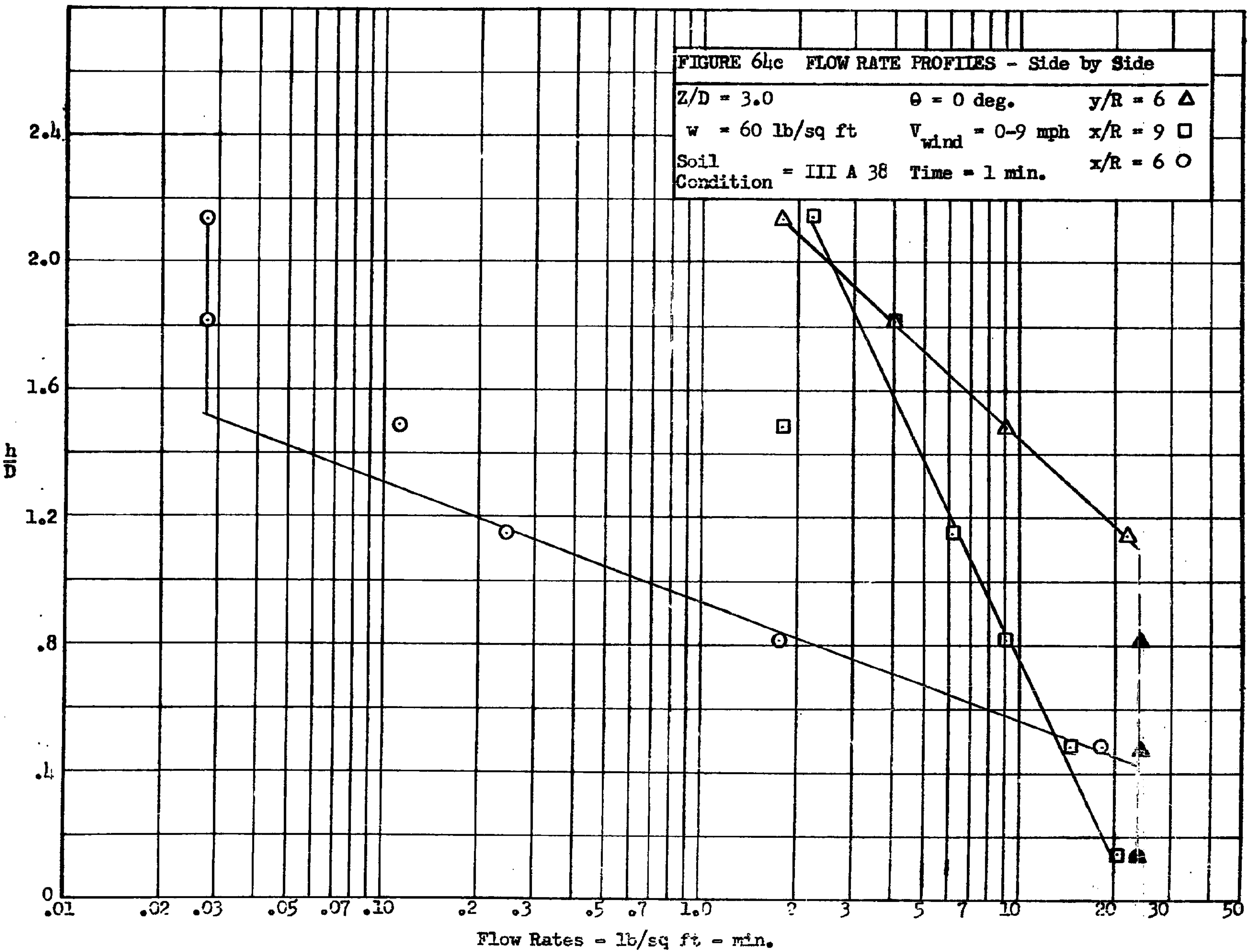


FIGURE 64c FLOW RATE PROFILES - Side by Side
Z/D = 3.0
θ = 0 deg.
y/R = 6 △
w = 60 lb/sq ft
V wind = 0-9 mph
x/R = 9 □
Soil Condition = III A 38
Time = 1 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

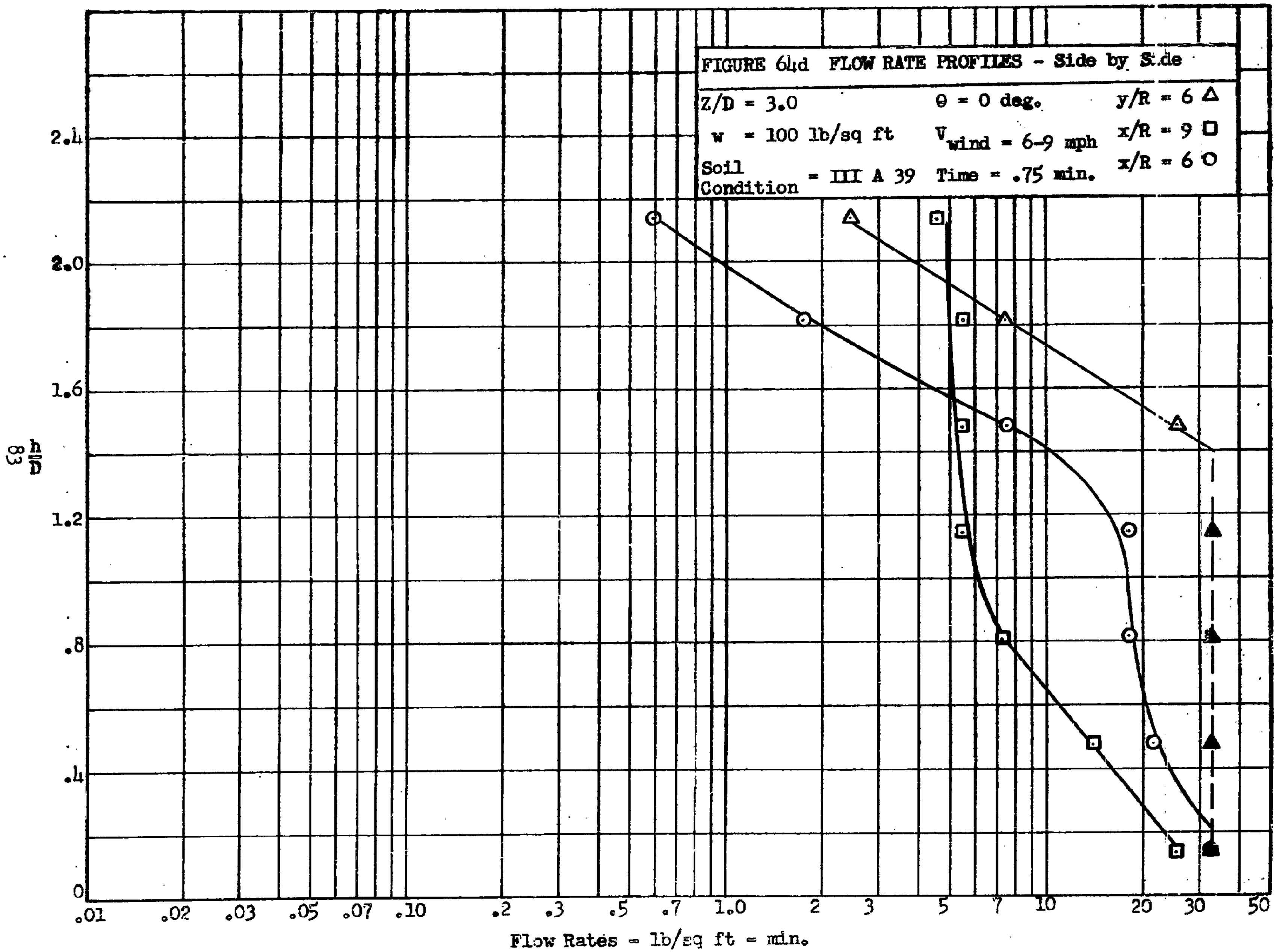


FIGURE 64d FLOW RATE PROFILES - Side by Side
Z/D = 3.0
θ = 0 deg.
y/R = 6 △
w = 100 lb/sq ft
V wind = 6-9 mph
x/R = 9 □
Soil Condition = III A 39
Time = .75 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates = lb/sq ft = min.

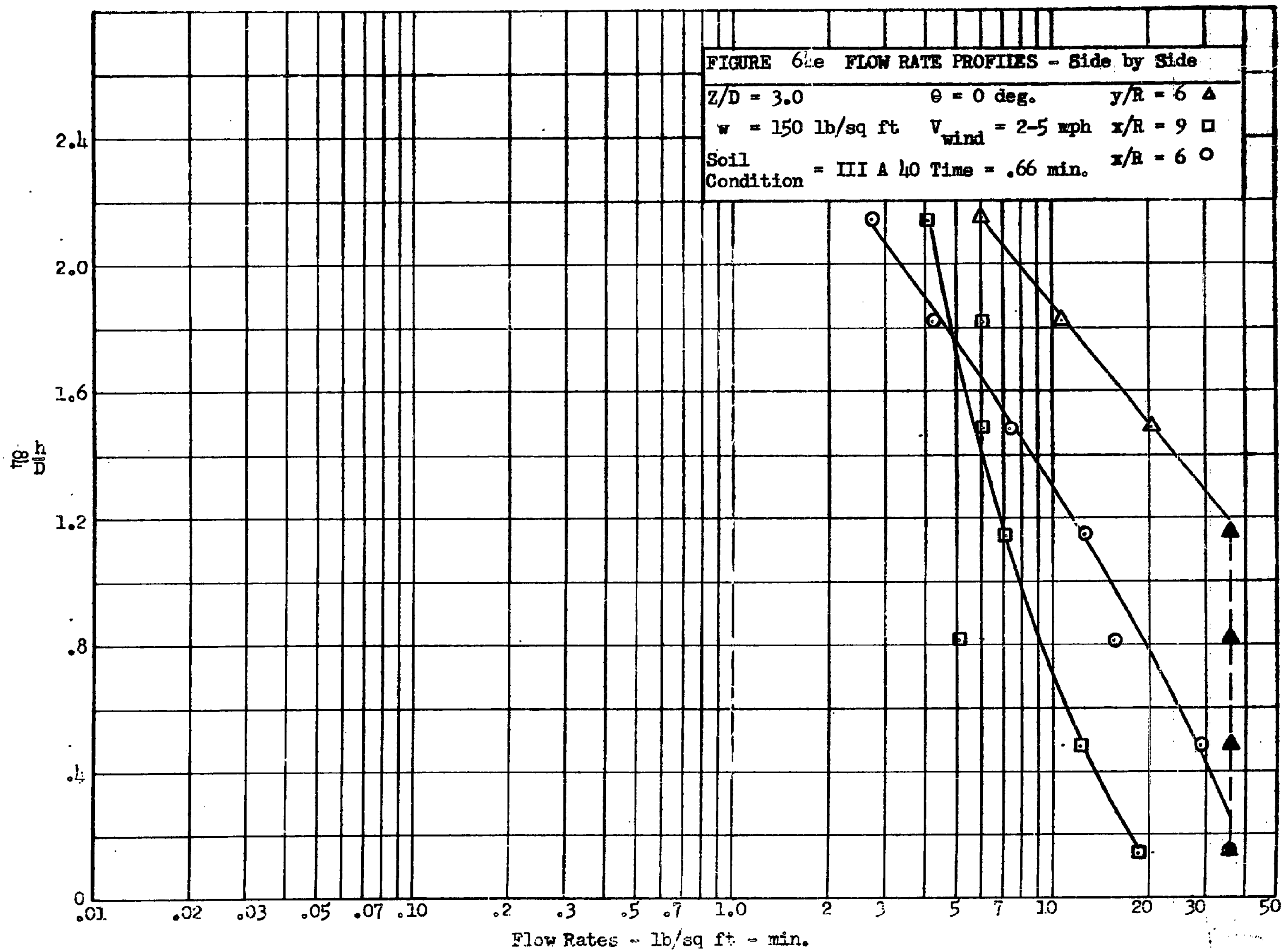


FIGURE 64e FLOW RATE PROFILES - Side by Side

Z/D = 3.0 θ = 0 deg. y/R = 6 △

w = 150 lb/sq ft V_{wind} = 2-5 mph x/R = 9 □

Soil Condition = III A 40 Time = .66 min. x/R = 6 ○

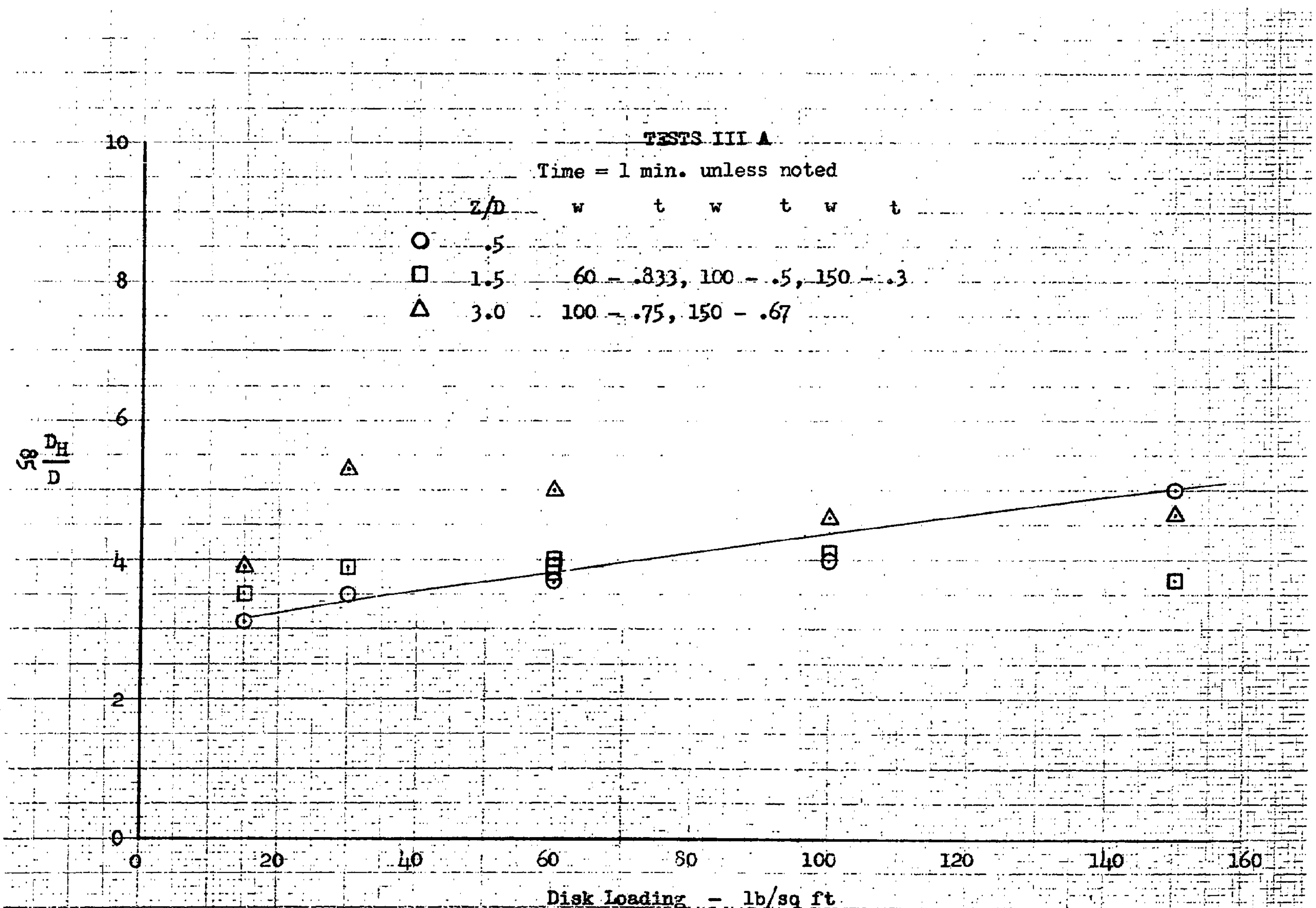


Figure 65 Relative Diameter of Eroded Section

E-12D

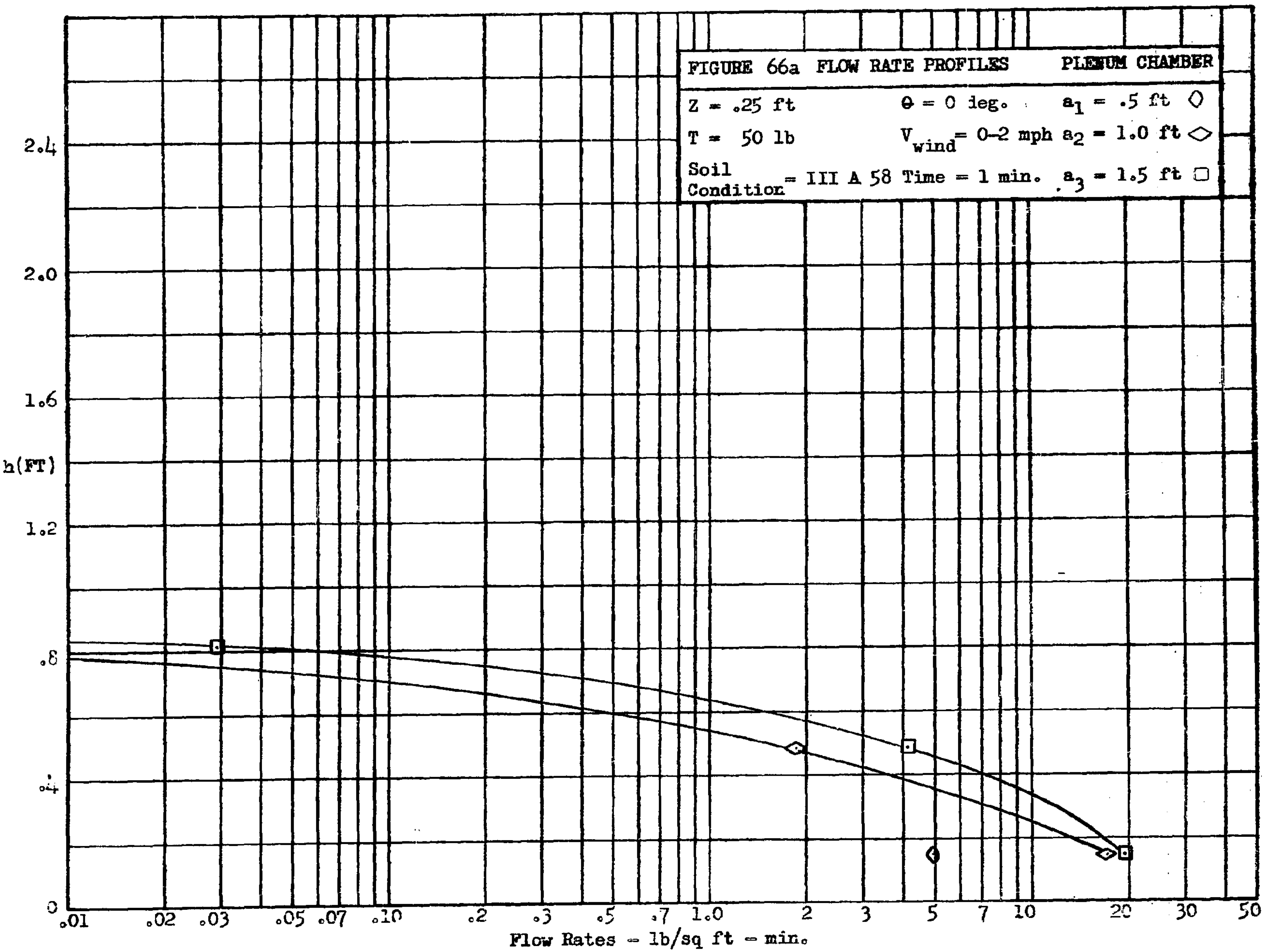


FIGURE 66a FLOW RATE PROFILES PLENUM CHAMBER
Z = .25 ft
θ = 0 deg.
a1 = .5 ft ◇
T = 50 lb
Vwind = 0-2 mph
a2 = 1.0 ft ◇
Soil Condition = III A 58
Time = 1 min.
a3 = 1.5 ft □
2.4
2.0
1.6
h(FT)
1.2
.8
.4
0
.01 .02 .03 .05 .07 .10 .2 .3 .5 .7 1.0 2 3 5 7 10 20 30 50
Flow Rates - lb/sq ft - min.

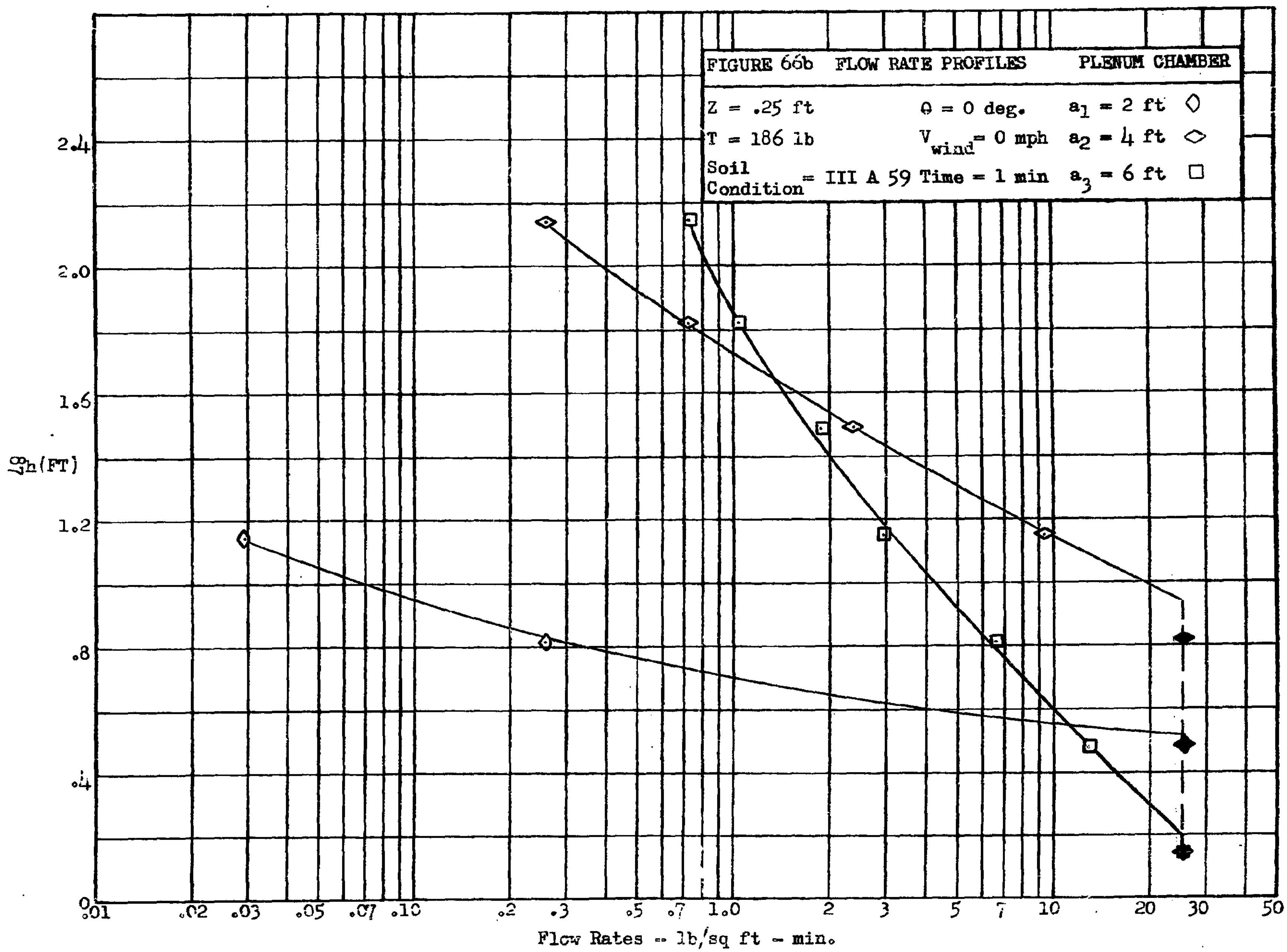


FIGURE 66b FLOW RATE PROFILES PLENUM CHAMBER
Z = .25 ft
θ = 0 deg.
a_1 = 2 ft
T = 186 lb
V_{wind} = 0 mph
a_2 = 4 ft
Soil Condition = III A 59
Time = 1 min
a_3 = 6 ft
2.4
2.0
1.6
1.2
.8
.4
0
ϖ_h(FT)
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates -- lb/sq ft - min.

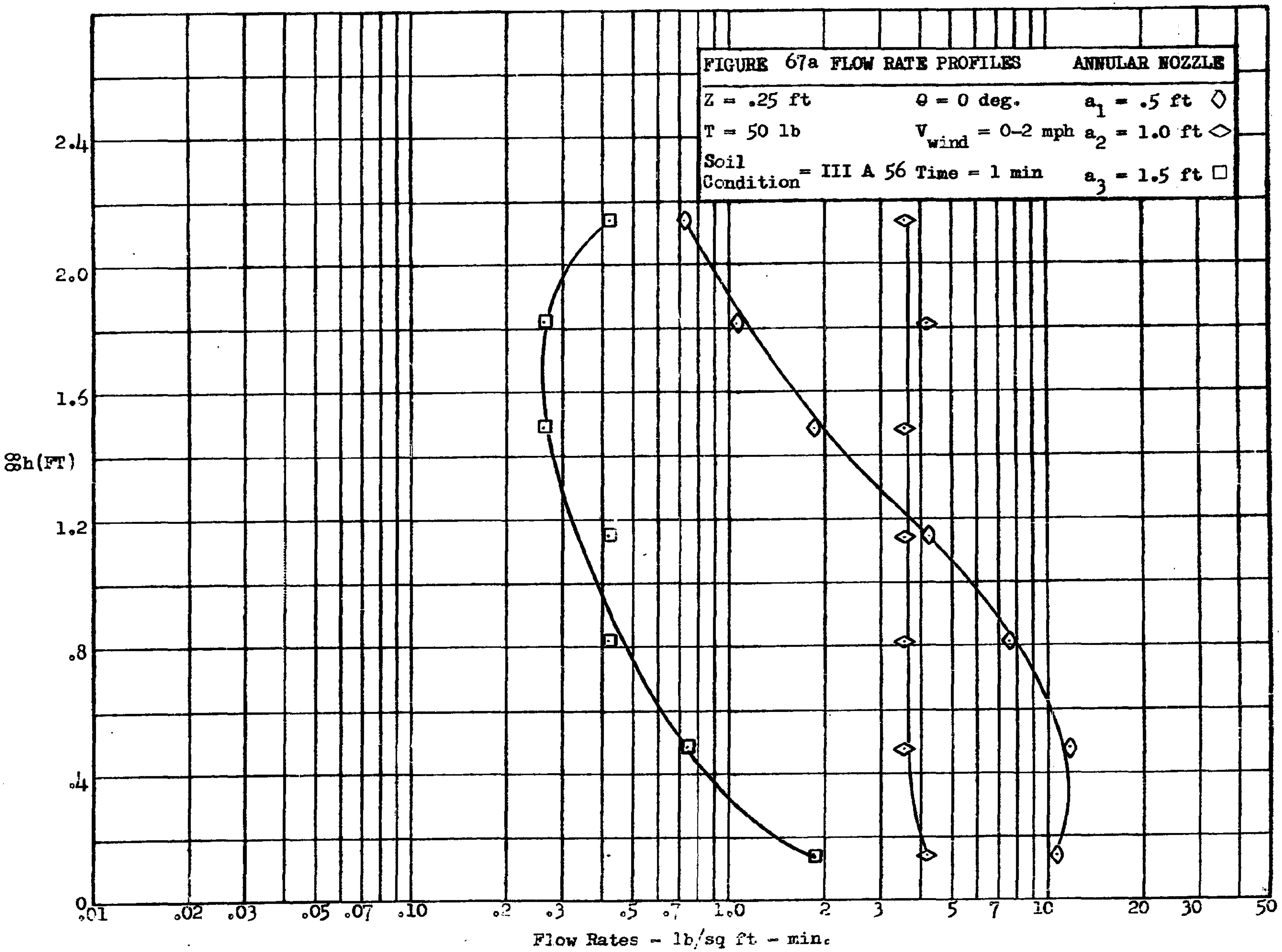


FIGURE 67a FLOW RATE PROFILES ANNULAR NOZZLE
Z = .25 ft
θ = 0 deg.
a_1 = .5 ft ◊
T = 50 lb
V_{wind} = 0-2 mph
a_2 = 1.0 ft ◇
Soil Condition = III A 56
Time = 1 min
a_3 = 1.5 ft □
δh(FT)
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min.

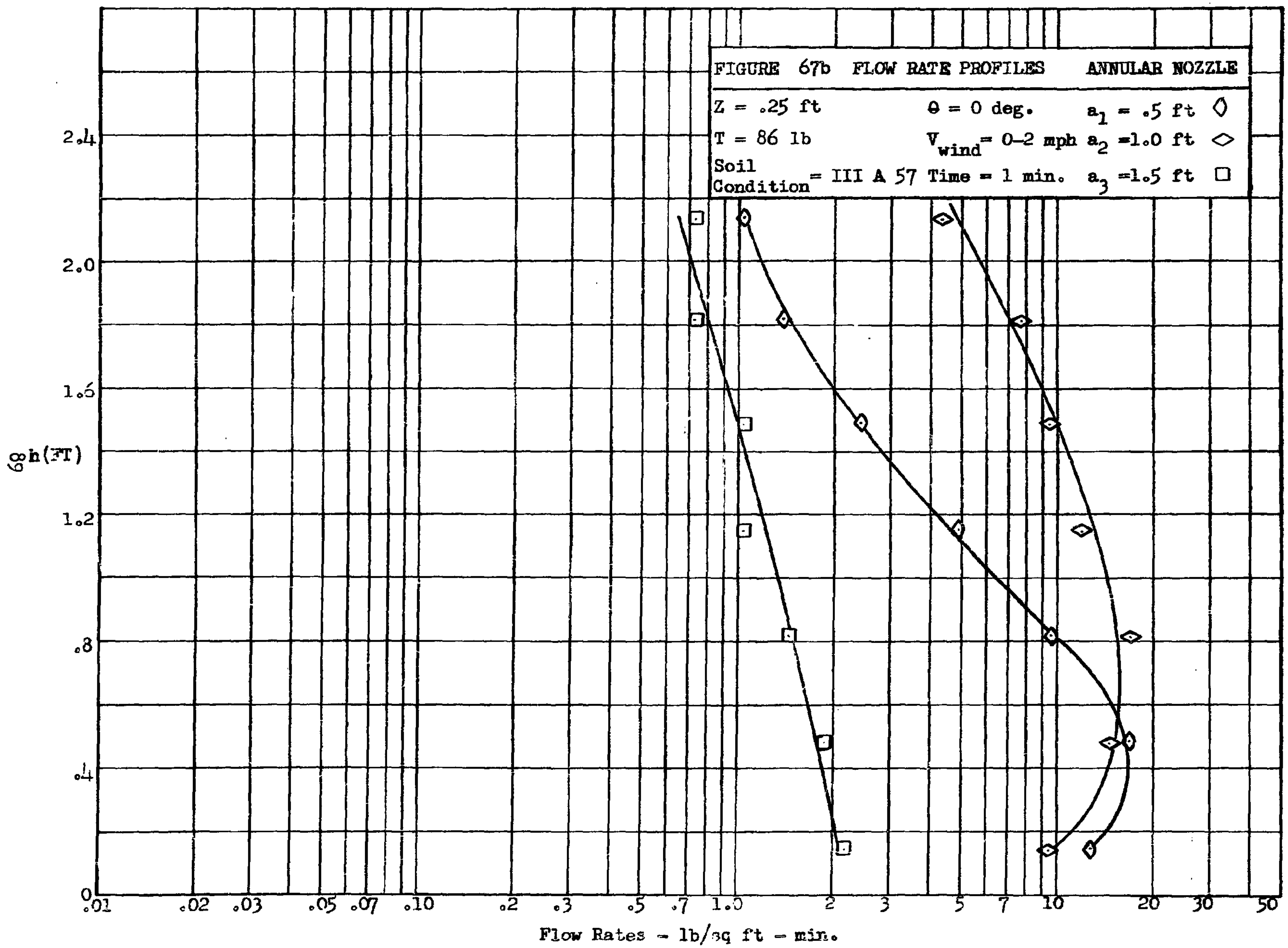


FIGURE 67b FLOW RATE PROFILES ANNULAR NOZZLE
Z = .25 ft
θ = 0 deg.
a_1 = .5 ft
T = 86 lb
V_{wind} = 0–2 mph
a_2 = 1.0 ft
Soil Condition = III A 57
Time = 1 min.
a_3 = 1.5 ft
h (FT)
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates – lb/sq ft – min.

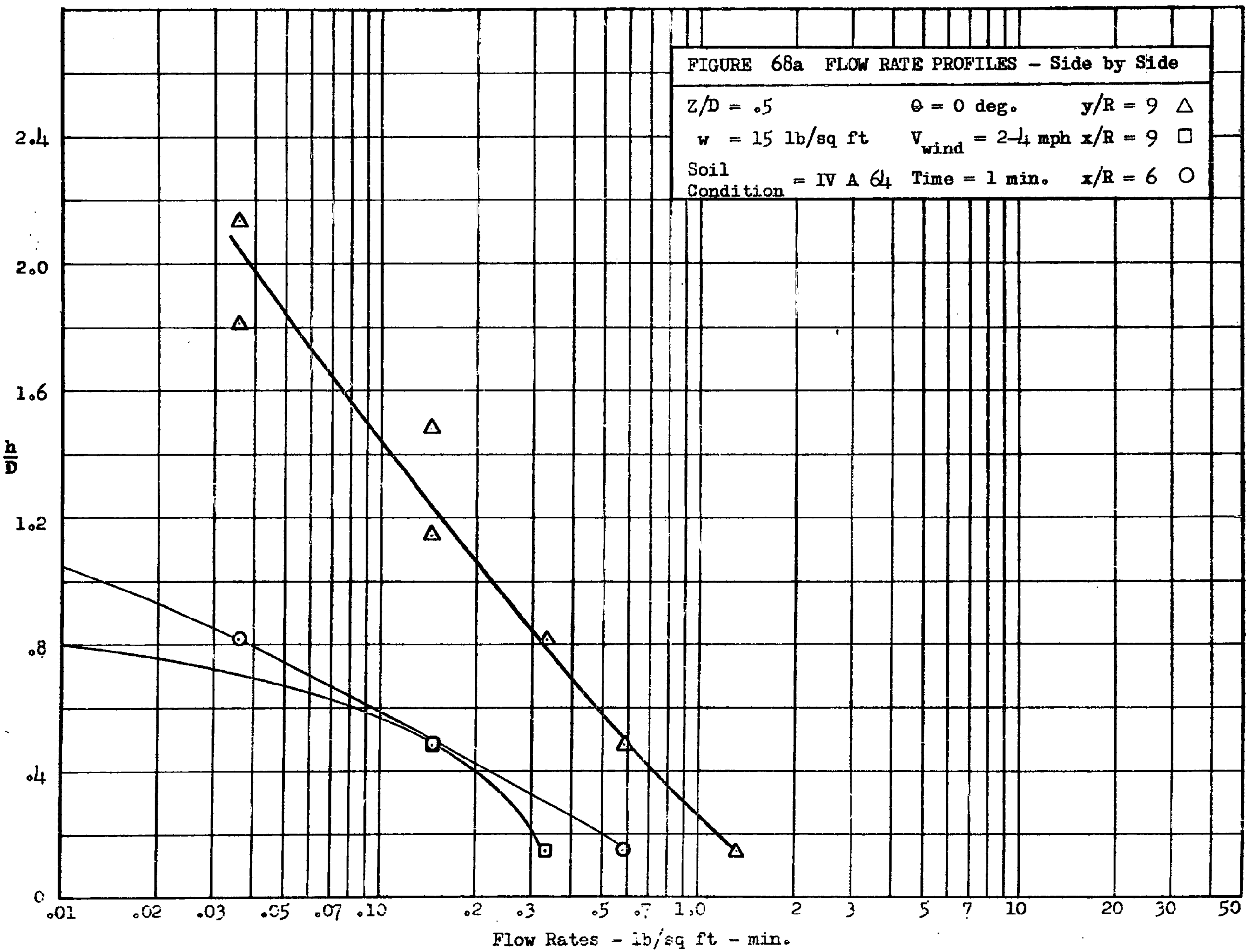


FIGURE 68a FLOW RATE PROFILES - Side by Side

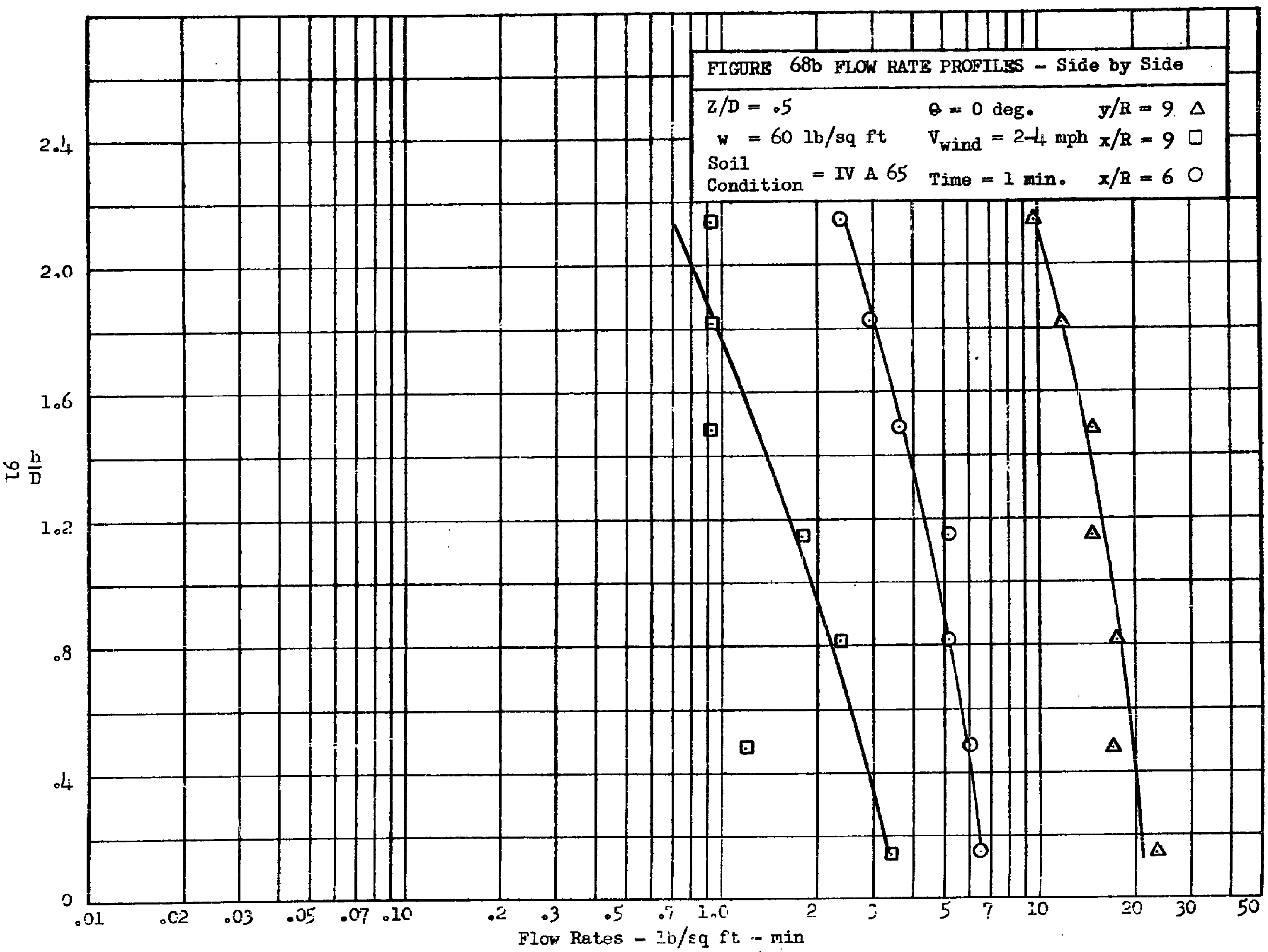


FIGURE 68b FLOW RATE PROFILES - Side by Side
Z/D = .5
w = 60 lb/sq ft
Soil Condition = IV A 65
θ = 0 deg.
V_wind = 2-4 mph
Time = 1 min.
y/R = 9 △
x/R = 9 □
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min

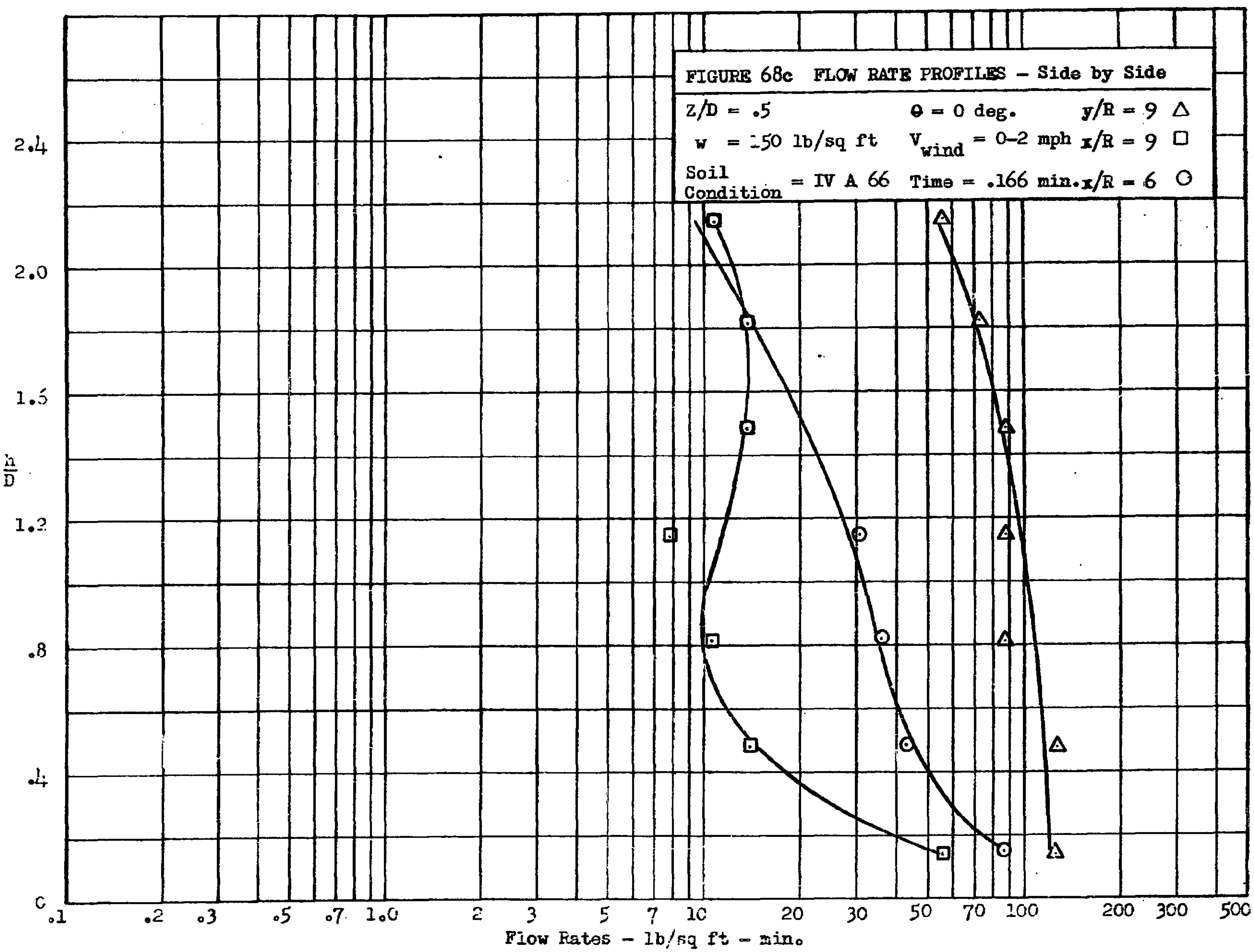


FIGURE 68c FLOW RATE PROFILES - Side by Side

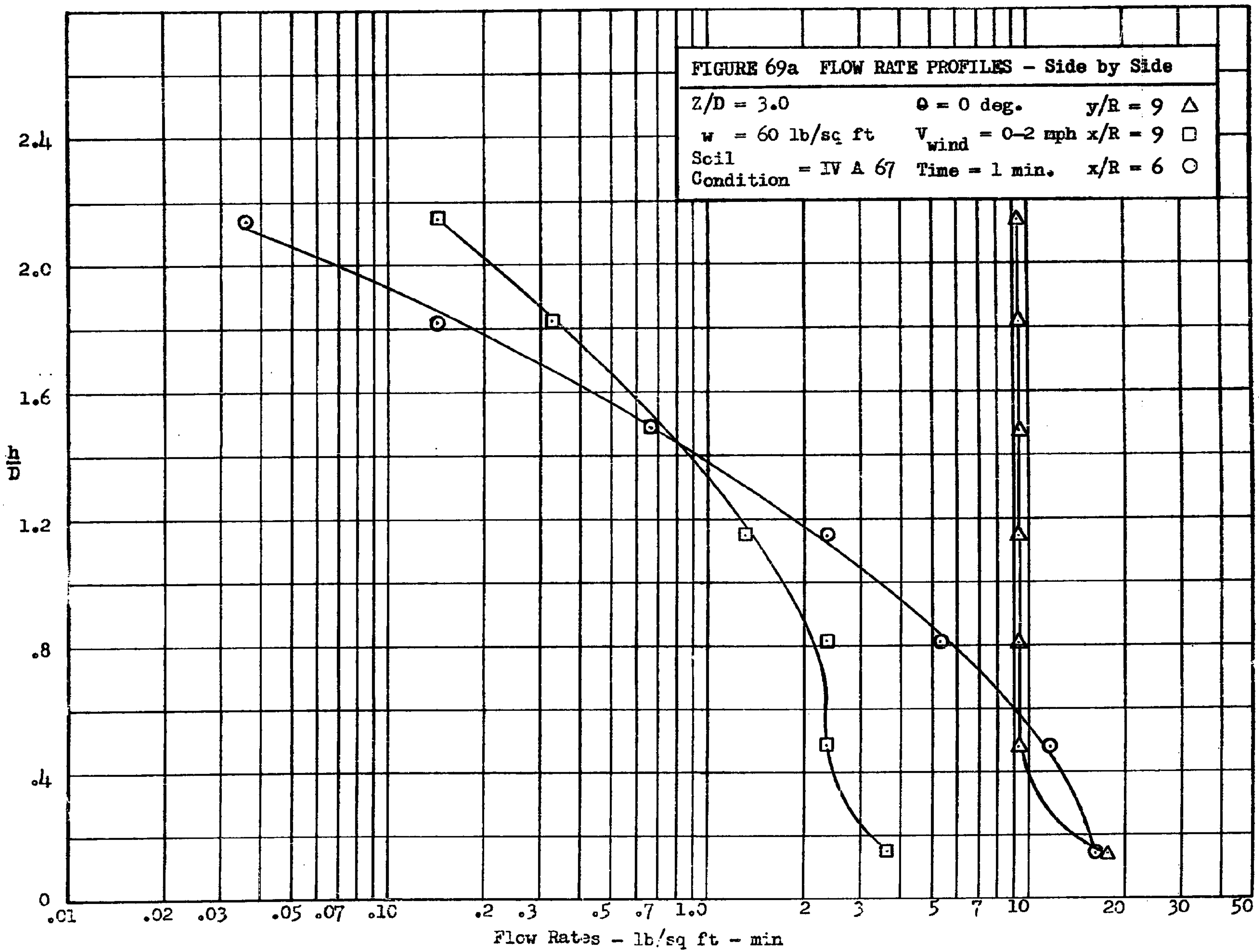


FIGURE 69a FLOW RATE PROFILES - Side by Side
Z/D = 3.0
w = 60 lb/sq ft
Soil Condition = IV A 67
θ = 0 deg.
V wind = 0-2 mph
Time = 1 min.
y/R = 9 △
x/R = 9 □
x/R = 6 ○
h/D
0
.4
.8
1.2
1.6
2.0
2.4
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min

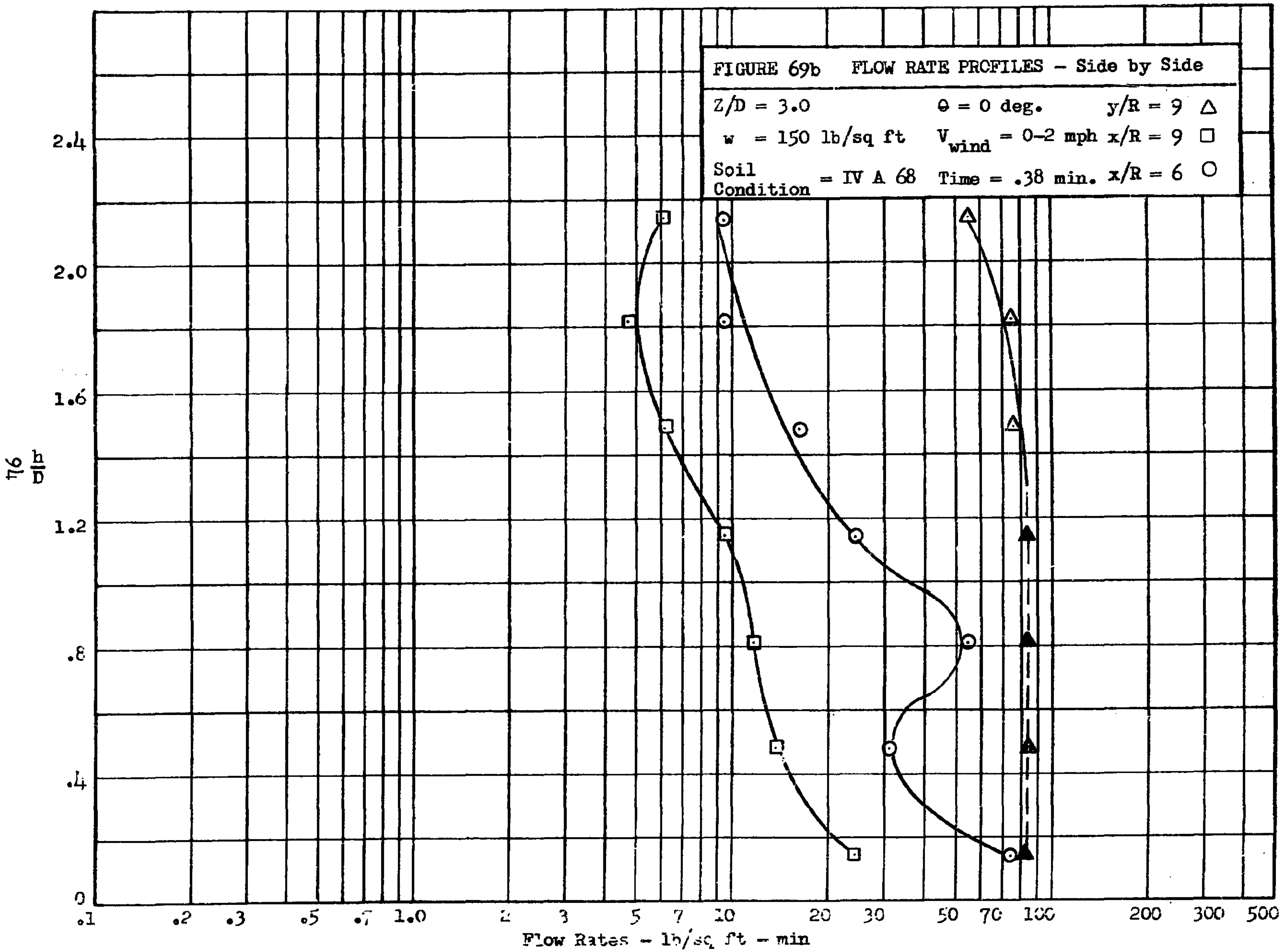


FIGURE 69b FLOW RATE PROFILES – Side by Side
Z/D = 3.0
θ = 0 deg.
y/R = 9 △
w = 150 lb/sq ft
V wind = 0-2 mph
x/R = 9 □
Soil Condition = IV A 68
Time = .38 min.
x/R = 6 ○
h/D
2.4
2.0
1.6
1.2
.8
.4
0
.1
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
70
100
200
300
500
Flow Rates – lb/sq ft – min

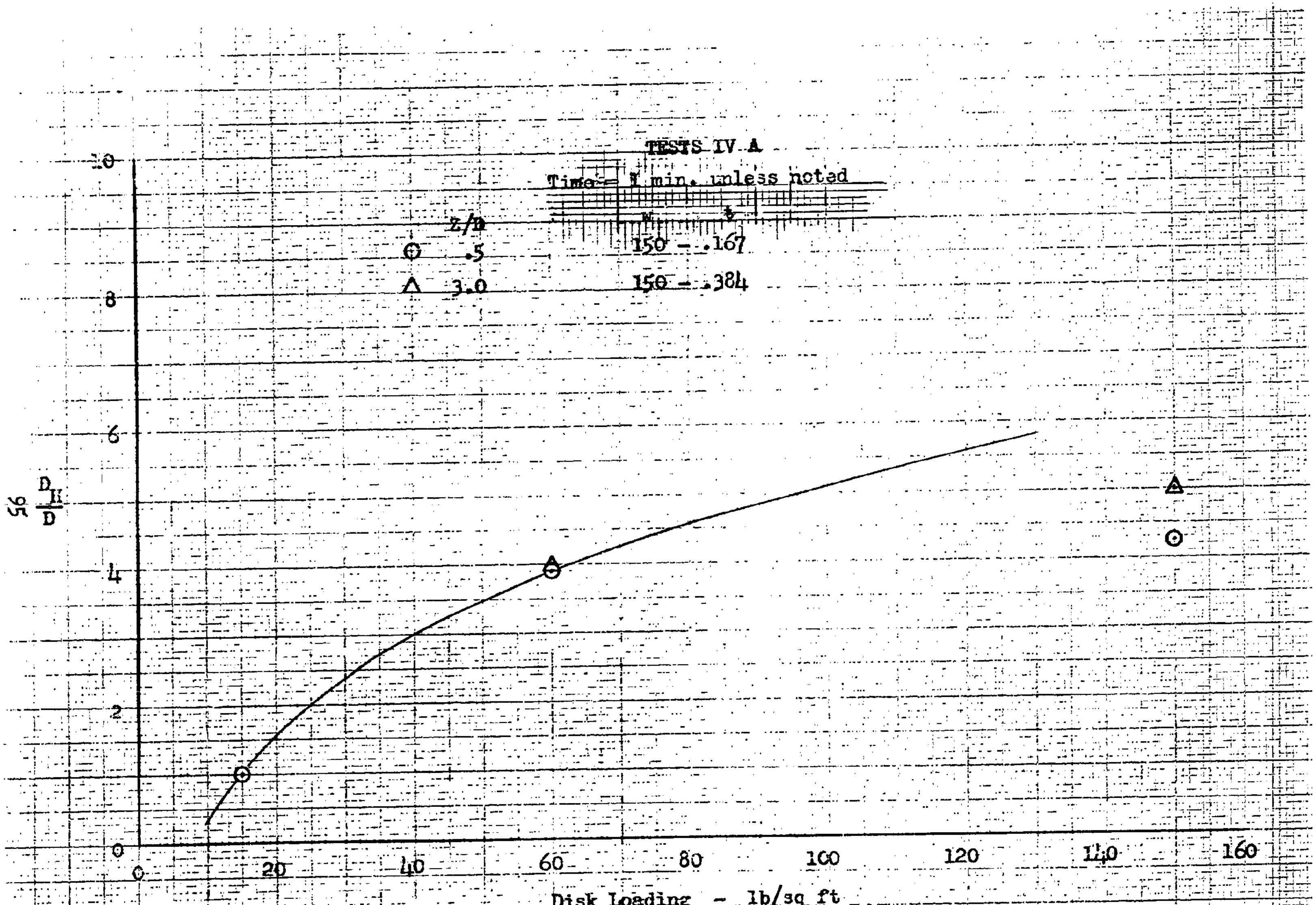


Figure 70 Relative Diameter of Eroded Section

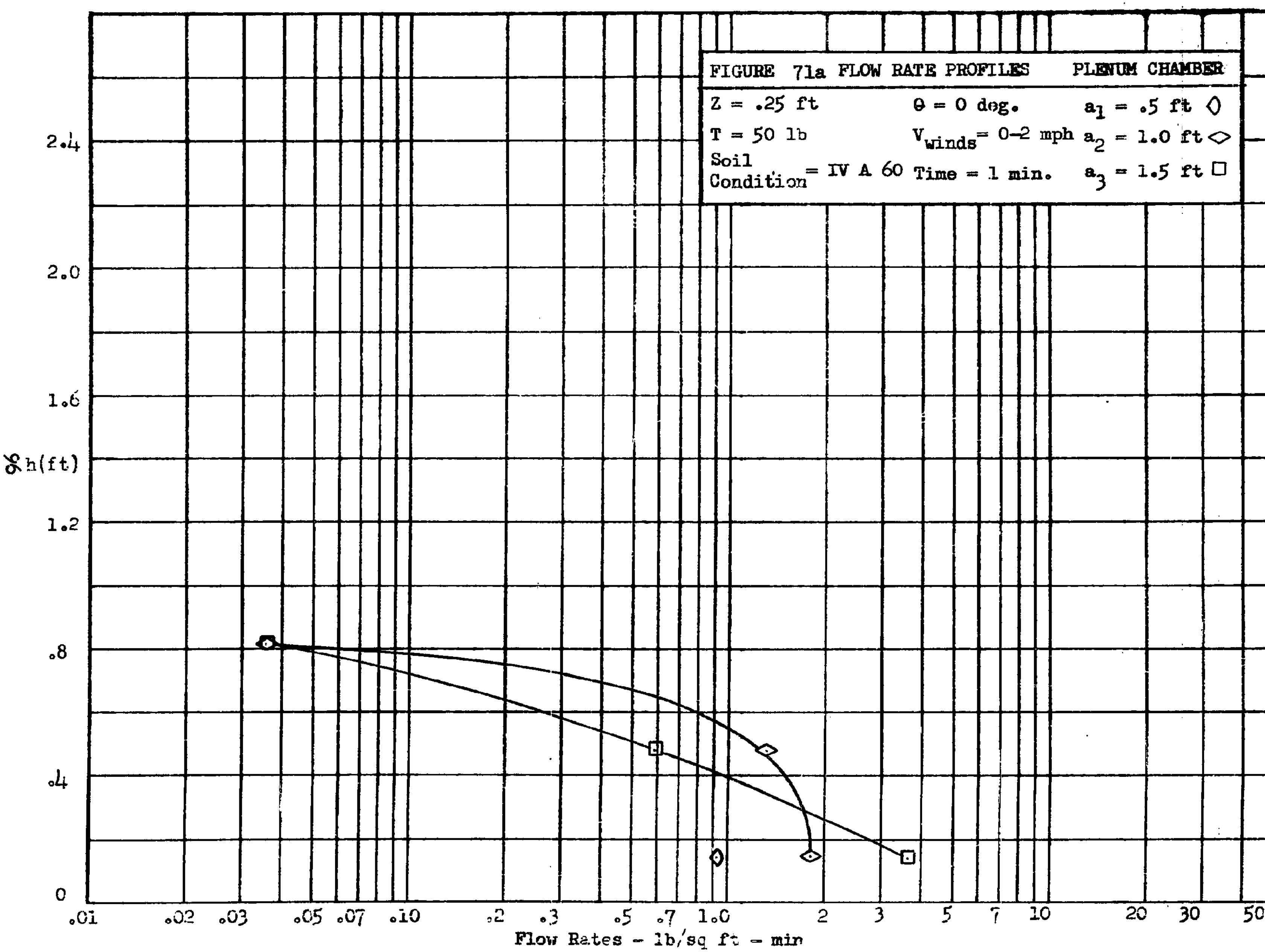


FIGURE 71a FLOW RATE PROFILES PLENUM CHAMBER
Z = .25 ft
θ = 0 deg.
a1 = .5 ft
T = 50 lb
Vwinds = 0-2 mph
a2 = 1.0 ft
Soil Condition = IV A 60
Time = 1 min.
a3 = 1.5 ft
h(ft)
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates - lb/sq ft - min

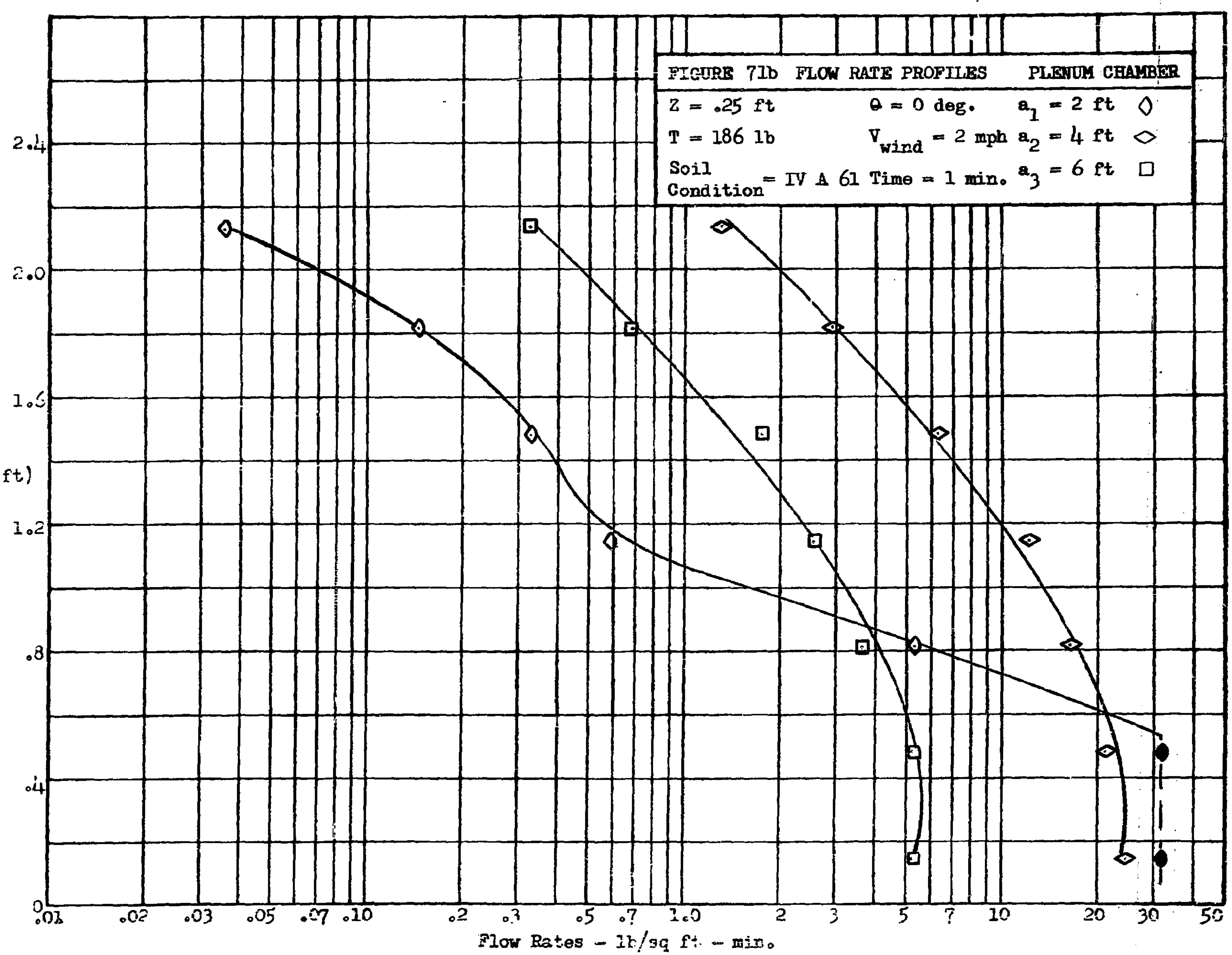


FIGURE 71b FLOW RATE PROFILES PLENUM CHAMBER
Z = .25 ft
θ = 0 deg.
a_1 = 2 ft
T = 186 lb
V_{wind} = 2 mph
a_2 = 4 ft
Soil Condition = IV A 61
Time = 1 min.
a_3 = 6 ft
h(ft)
Flow Rates - lb/sq ft - min.

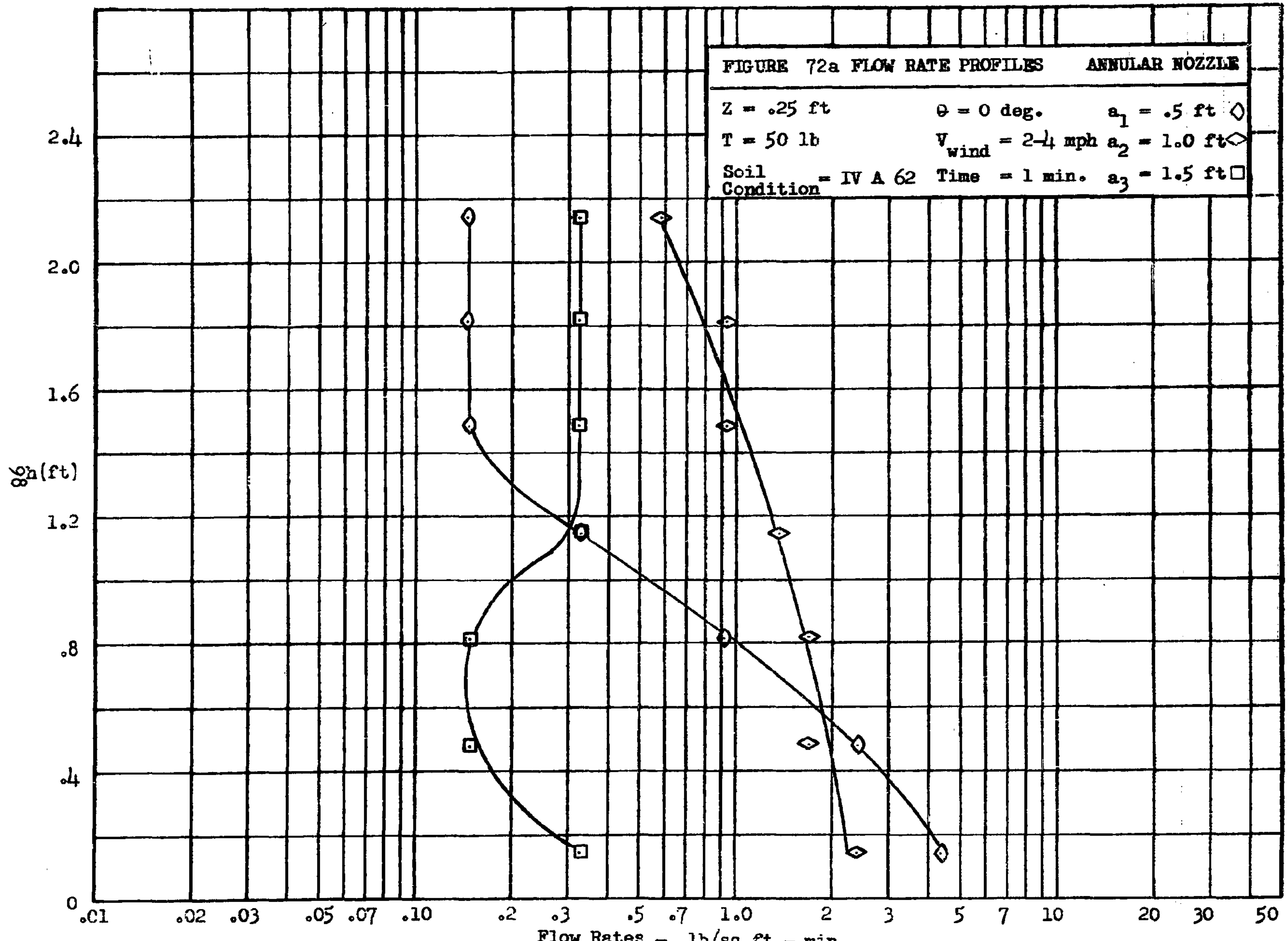


FIGURE 72a FLOW RATE PROFILES ANNULAR NOZZLE
Z = .25 ft
T = 50 lb
Soil Condition = IV A 62
θ = 0 deg.
V wind = 2-4 mph
Time = 1 min.
a1 = .5 ft
a2 = 1.0 ft
a3 = 1.5 ft
h(ft)
2.4
2.0
1.6
1.2
.8
.4
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rates – lb/sq ft – min.

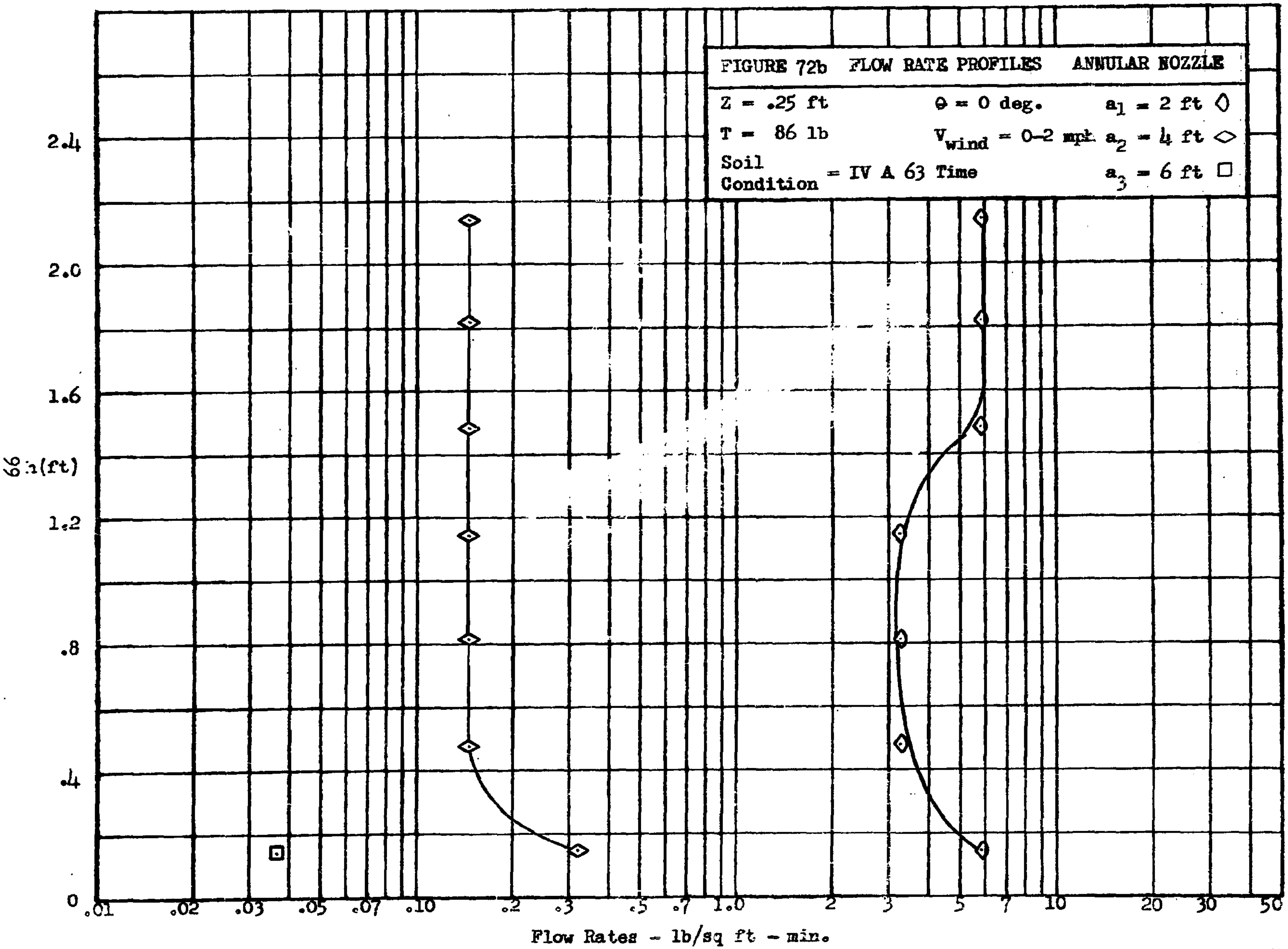


FIGURE 72b FLOW RATE PROFILES ANNULAR NOZZLE

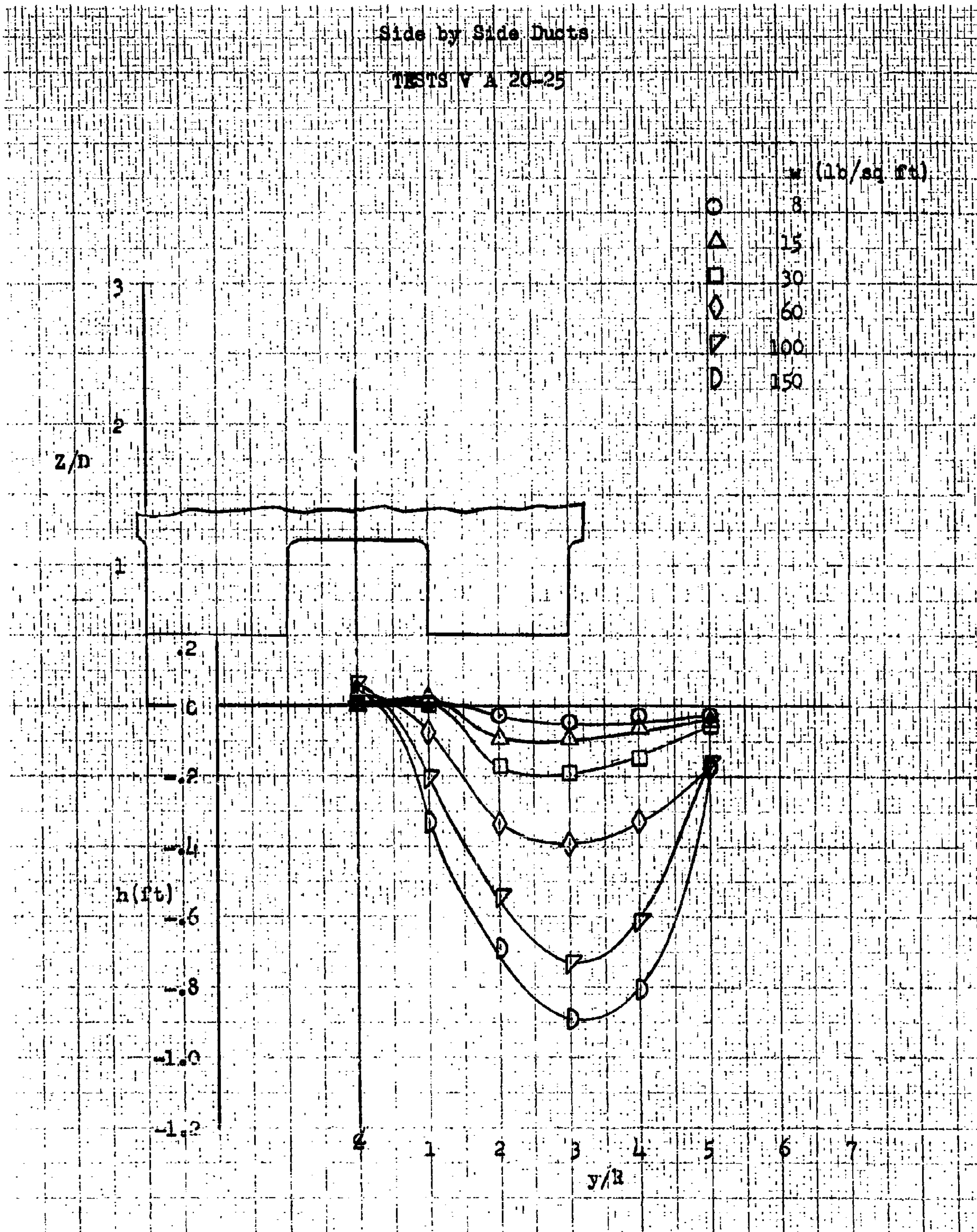


Figure 73 Water Surface Displacement

K-12D

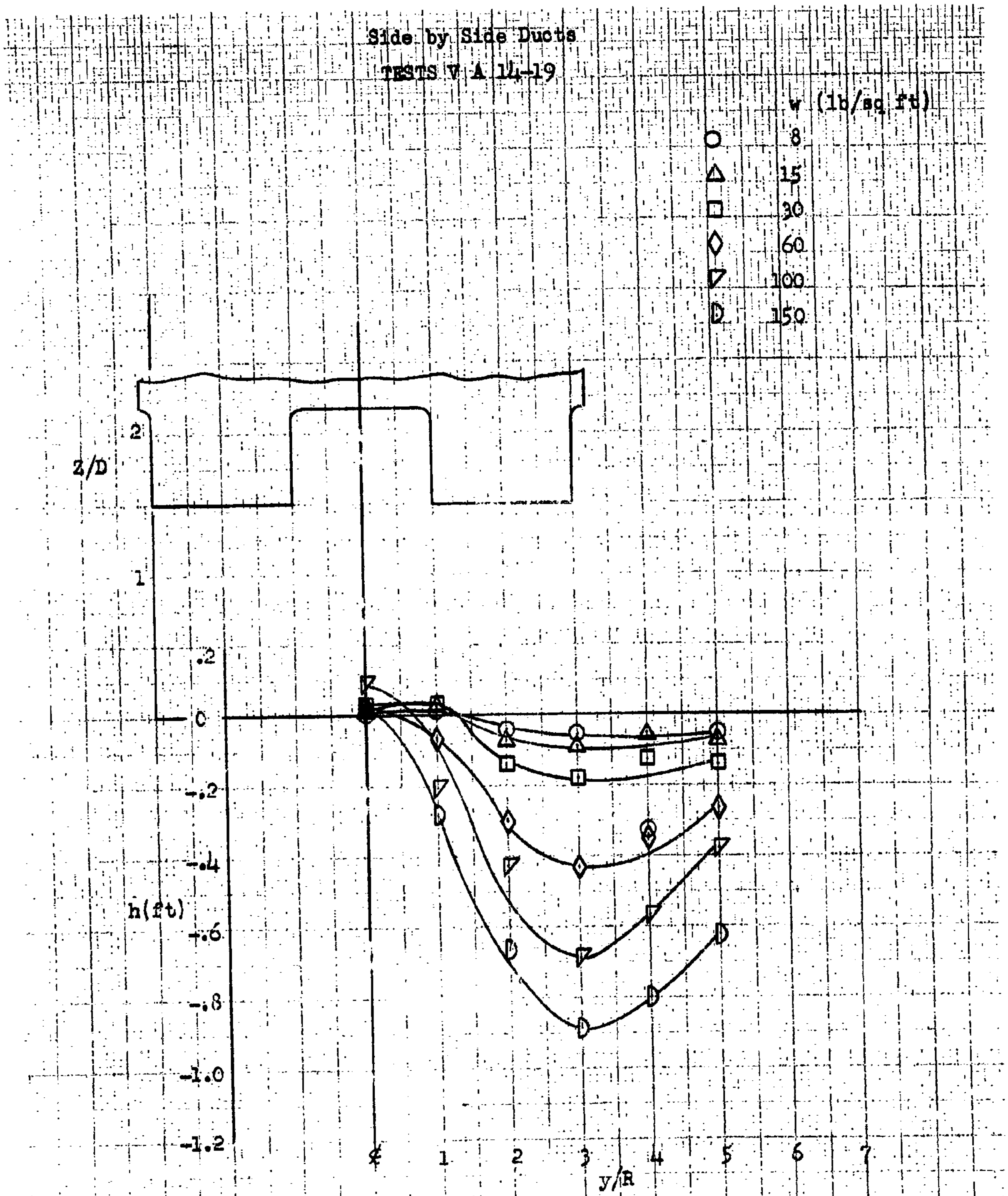


Figure 74 Water Surface Displacement

E-12D

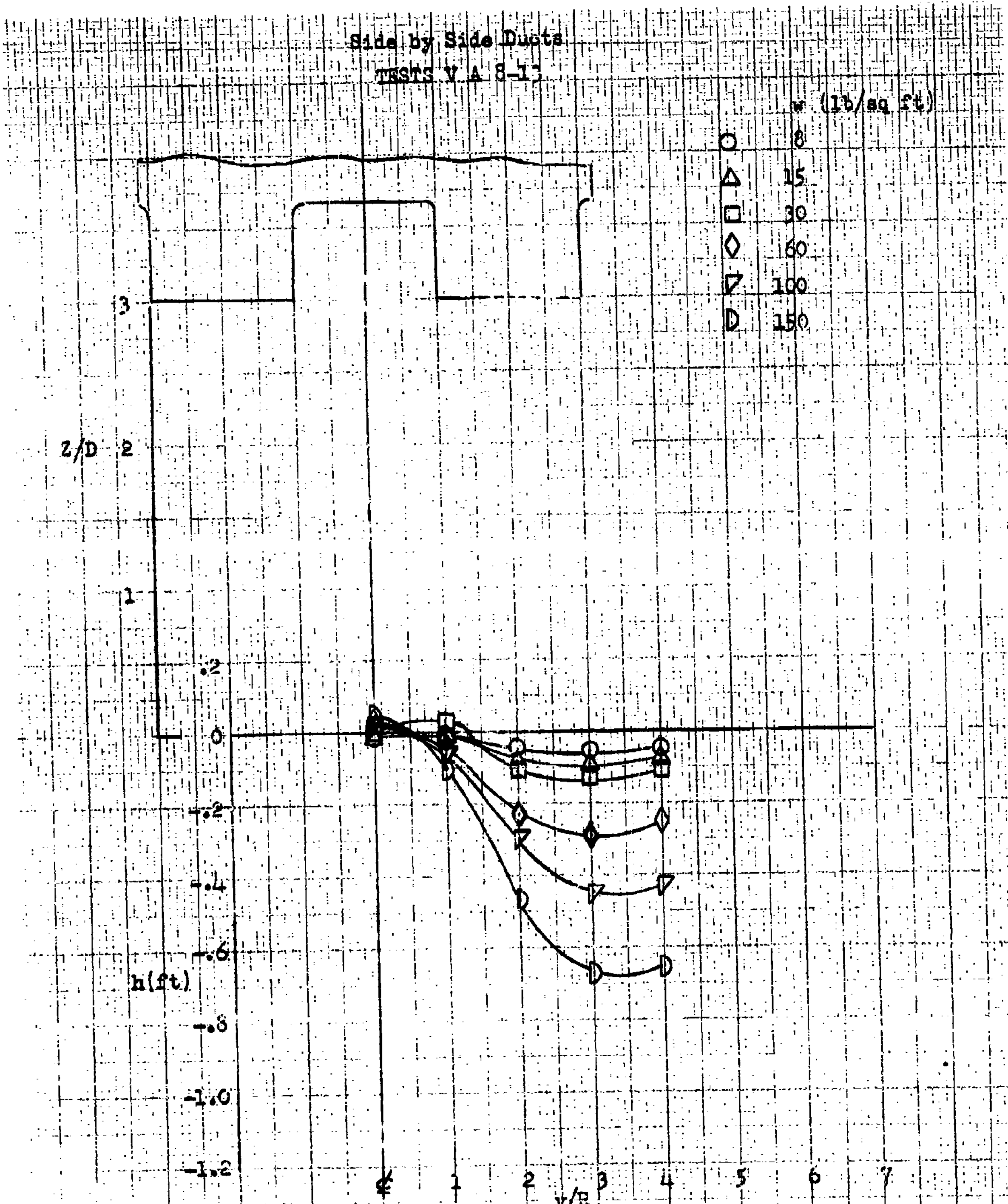


Figure 75 Water Surface Displacement

E-12D

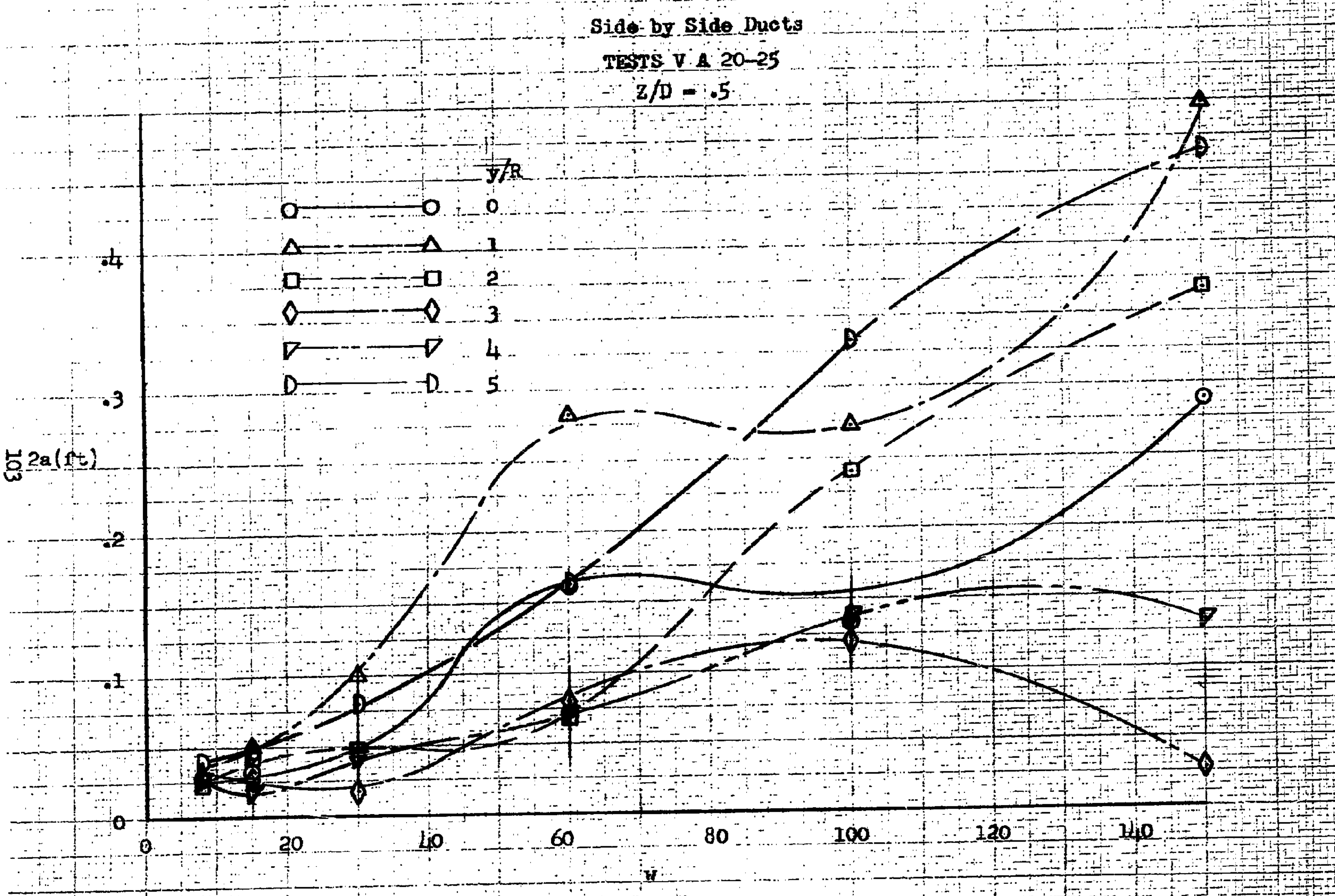


Figure 76a Wave Amplitude

E-12D

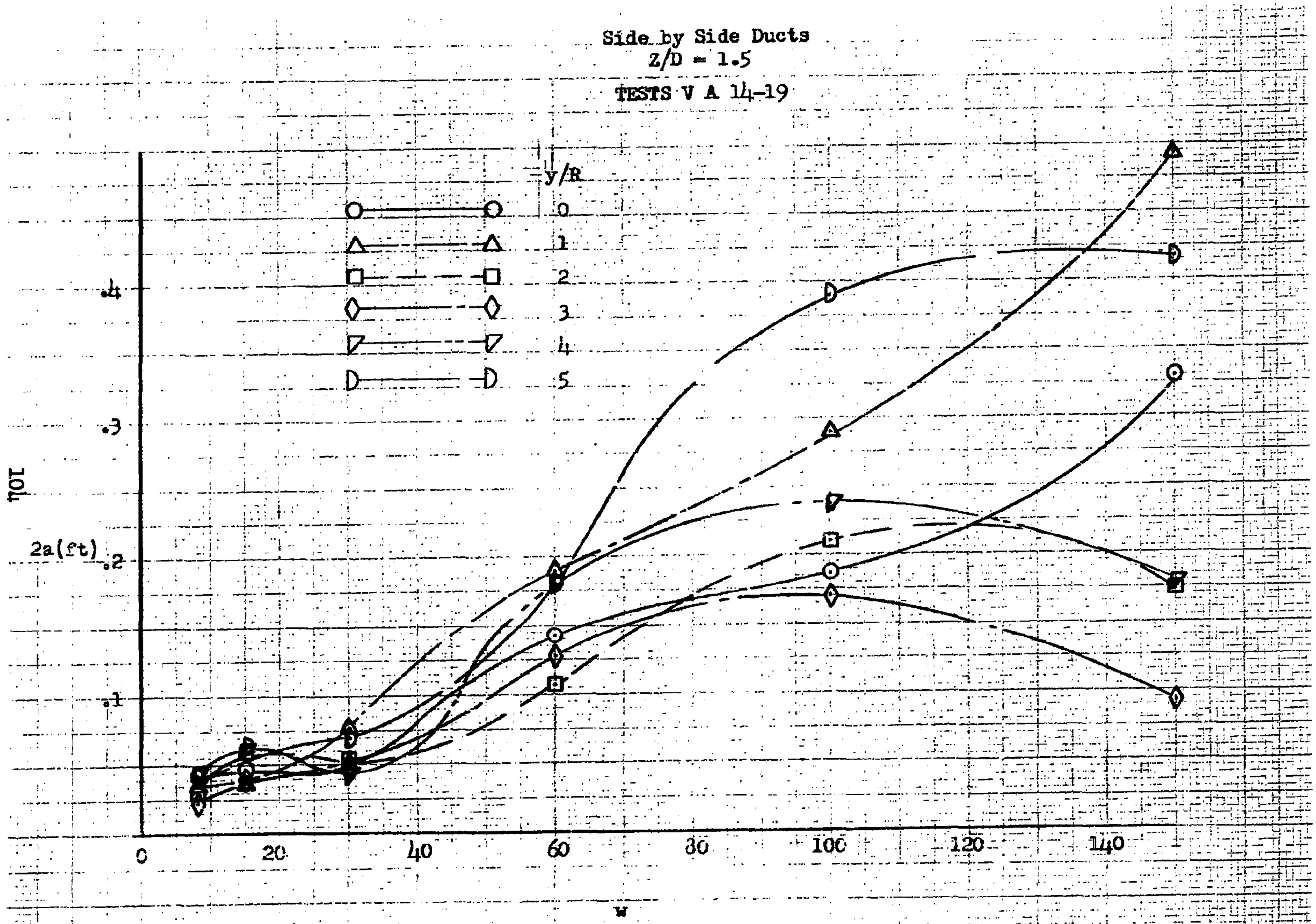


Figure 76b Wave Amplitude

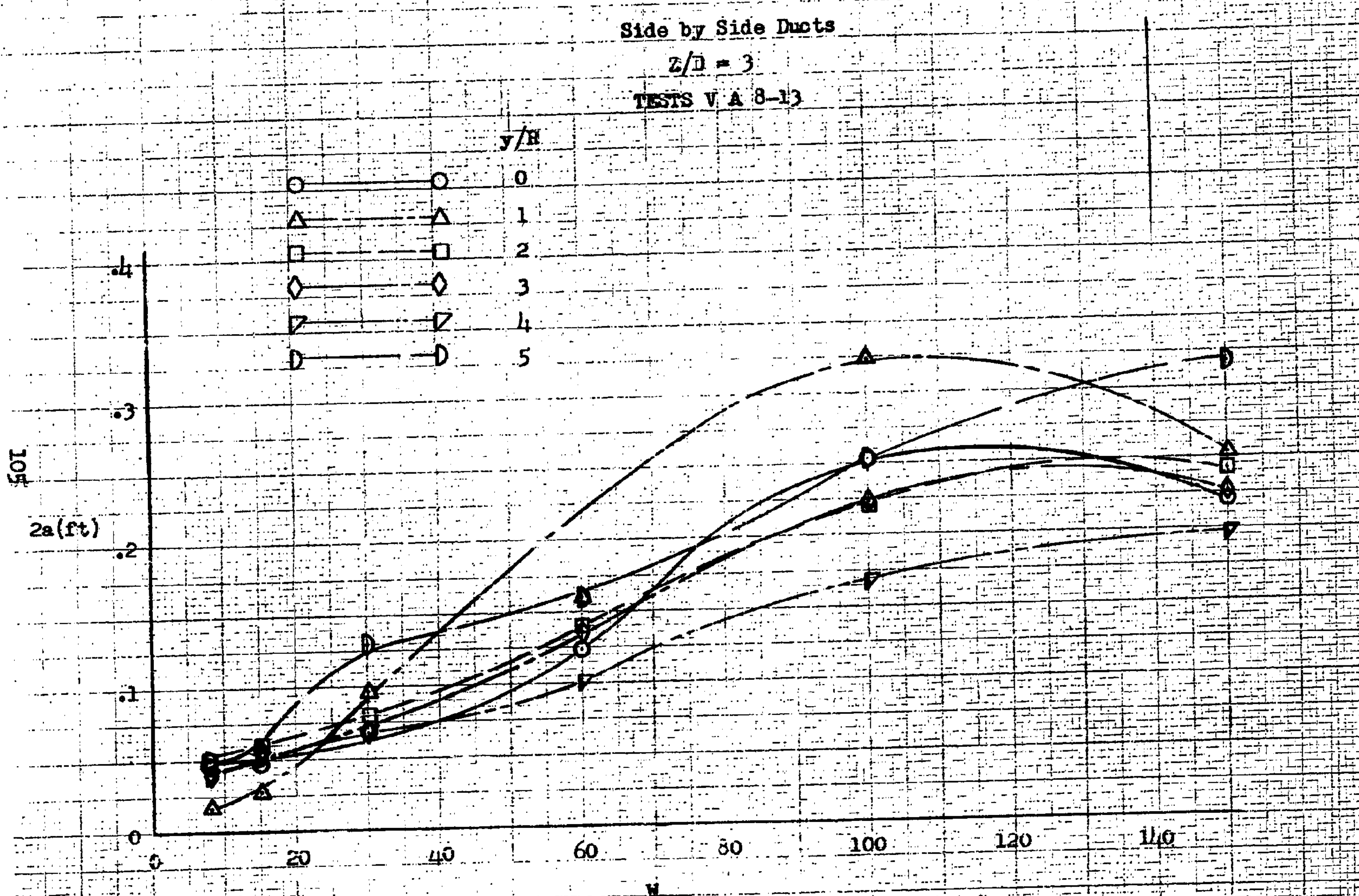


Figure 76c Wave Amplitude

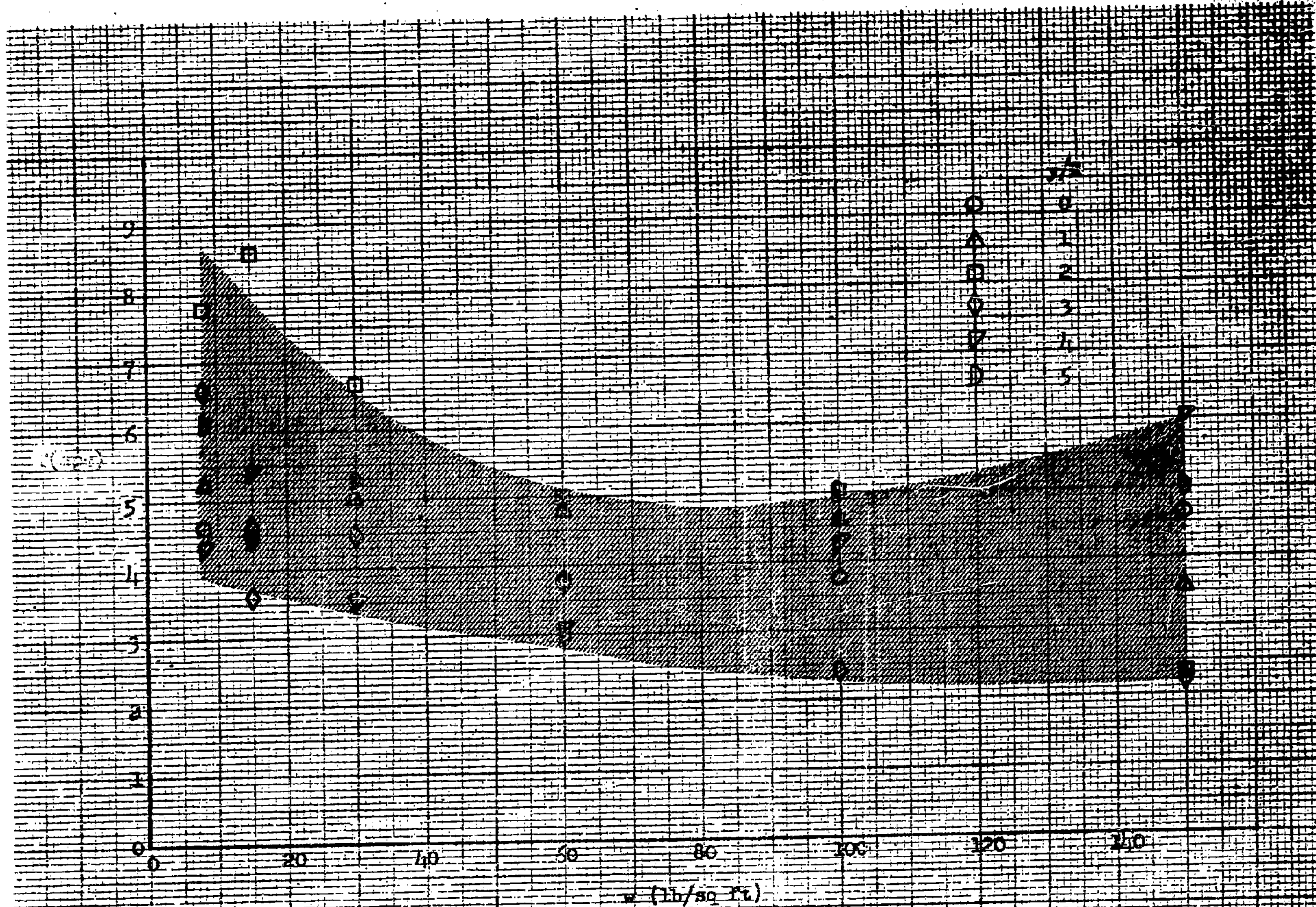


Figure Wave Frequency, Side by Side Ducts (z/D = .5)

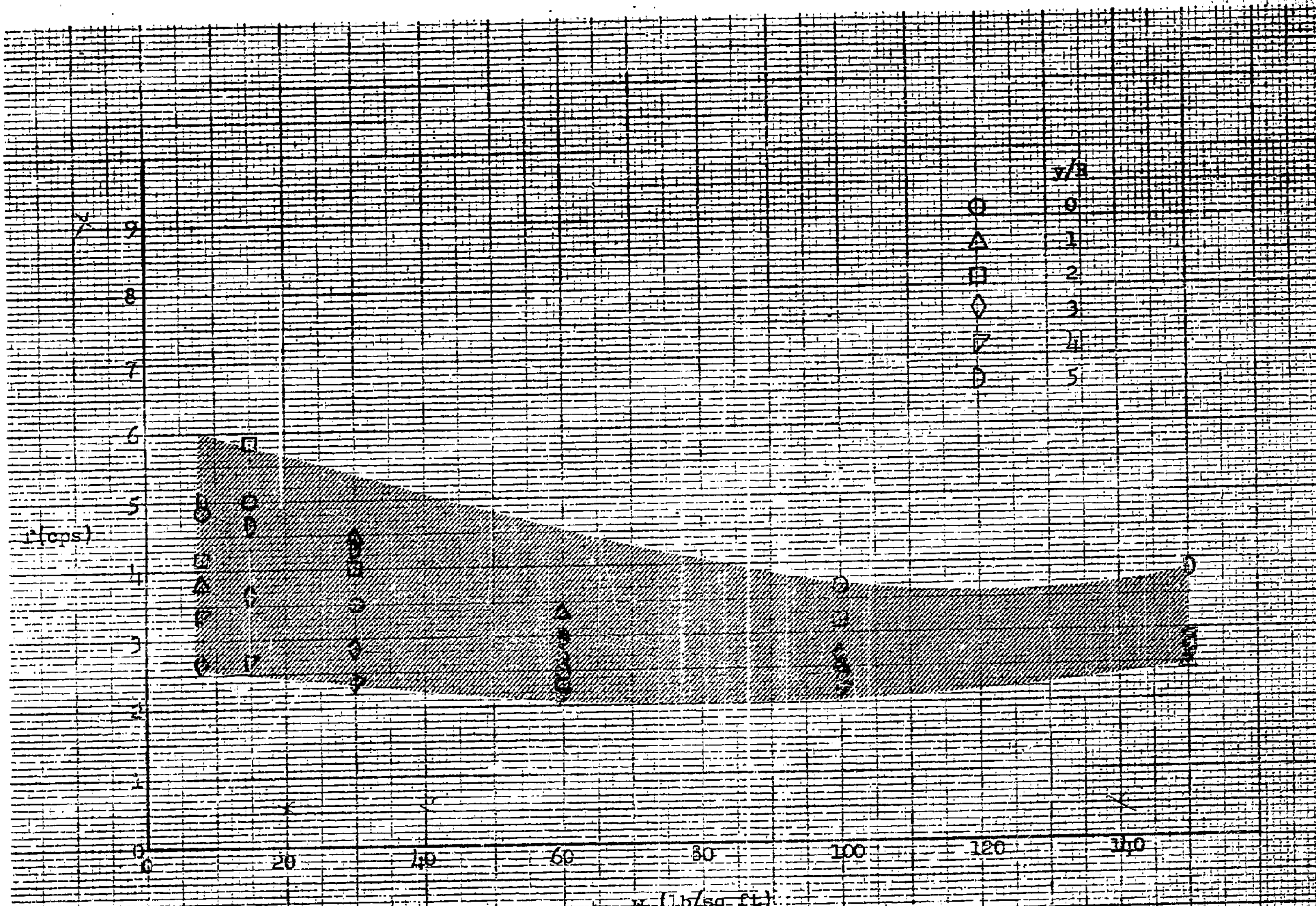


Figure . Wave Frequency, Side by Side Ducts (Z/D = 1.5)

E-12D

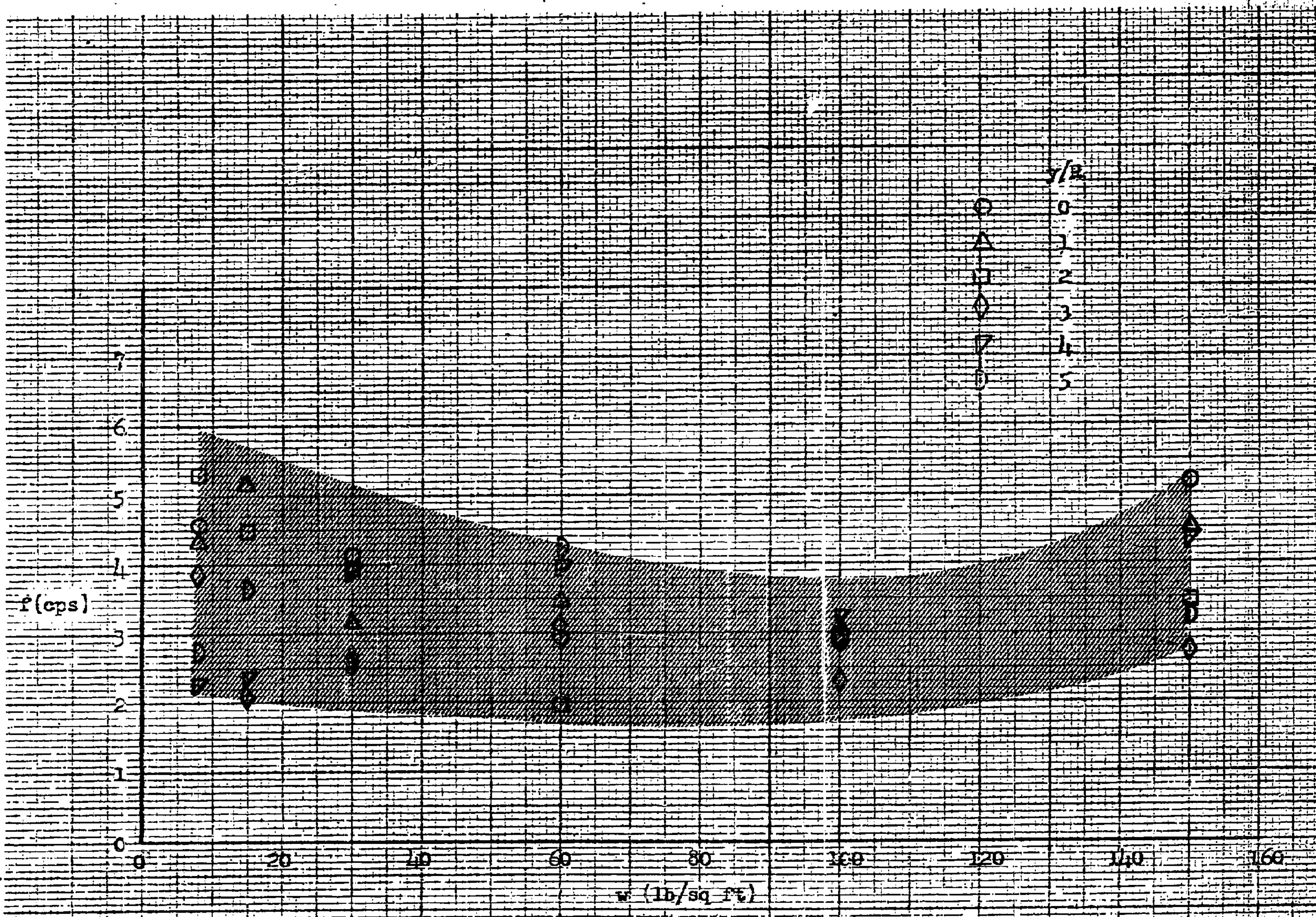


Figure [illegible] Wave Frequency, Side x Side Ducts (Z/D = 3.0)

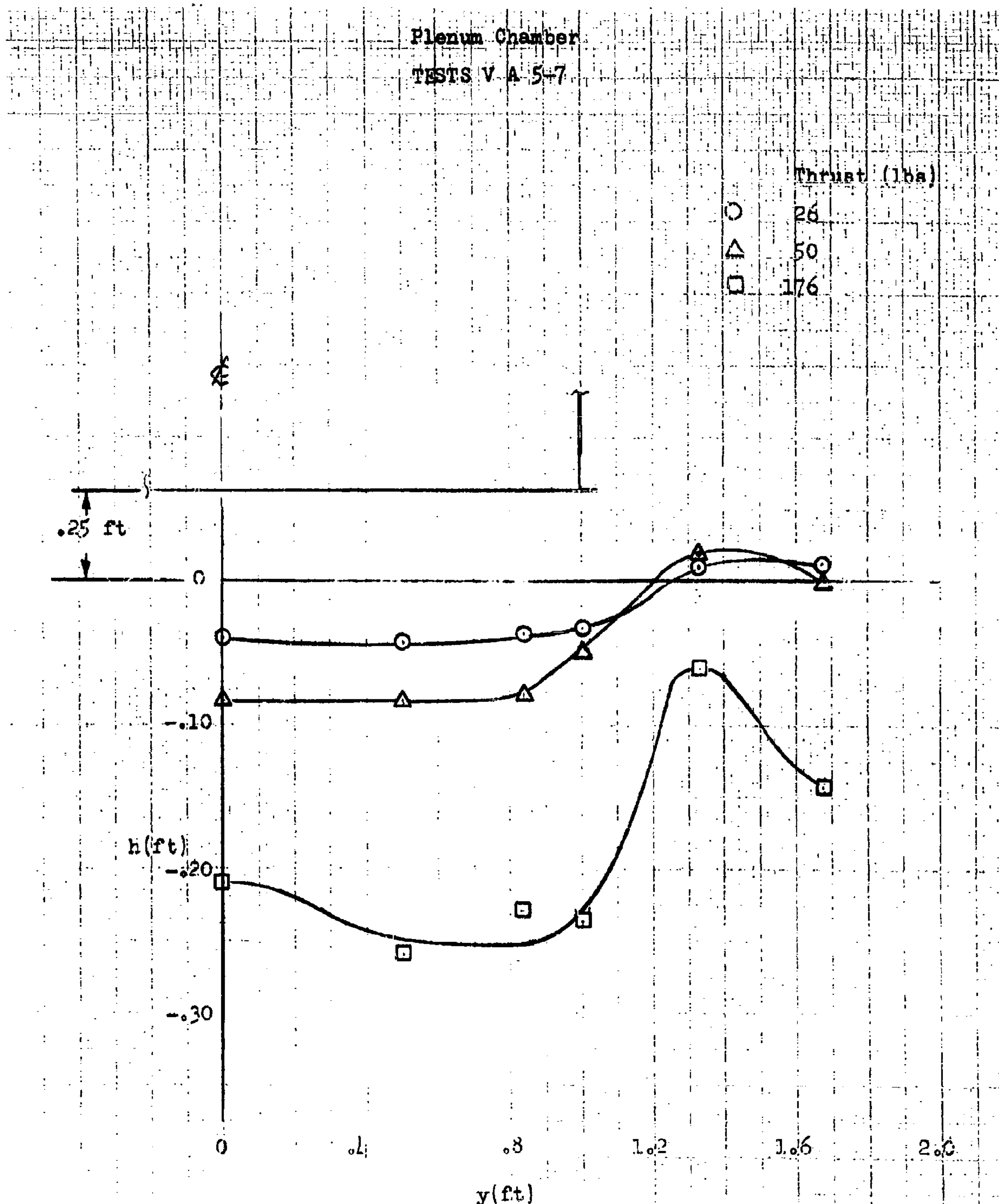


Figure 78 Water Surface Displacement

E-12D

Plenum Chamber

Z = .25 ft.

TESTS V A 5-7

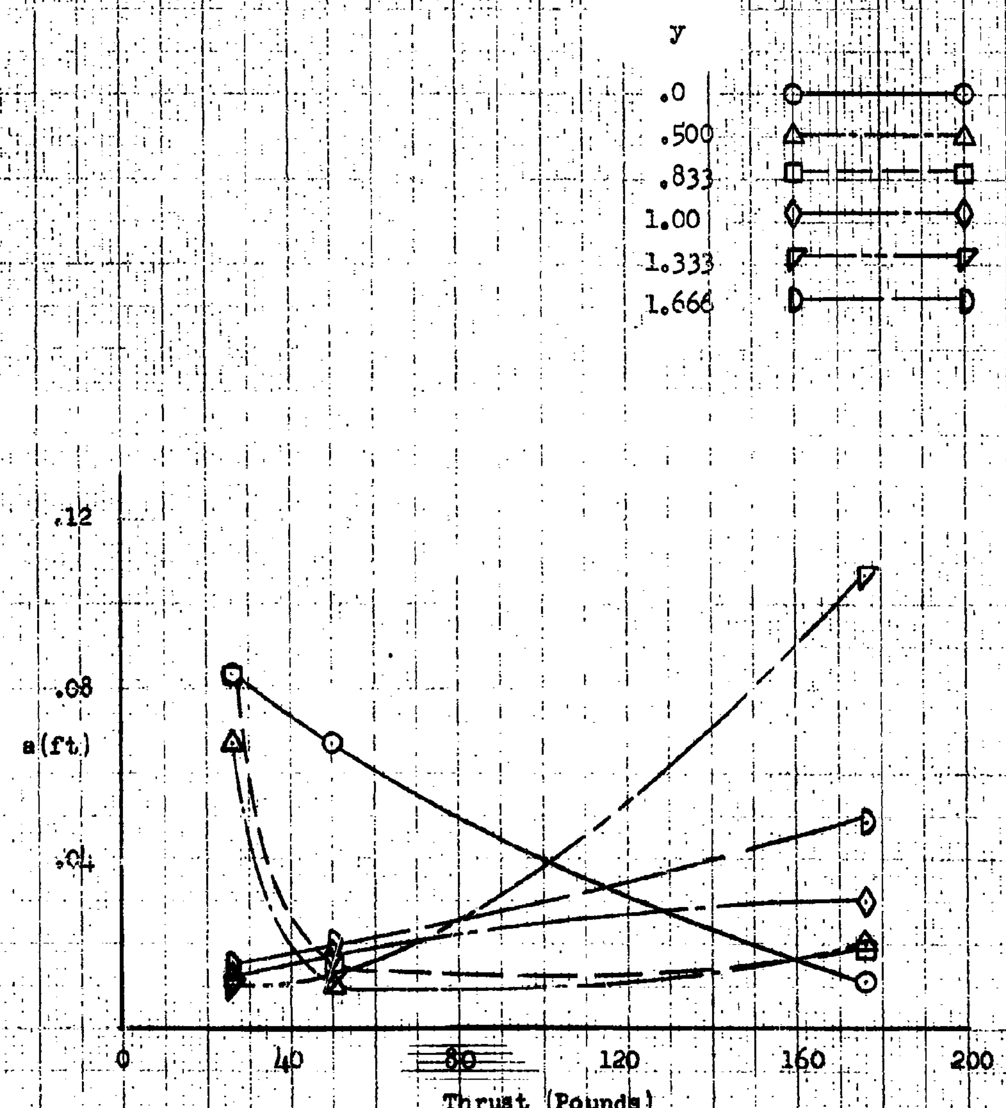


Figure 79 Wave Amplitude

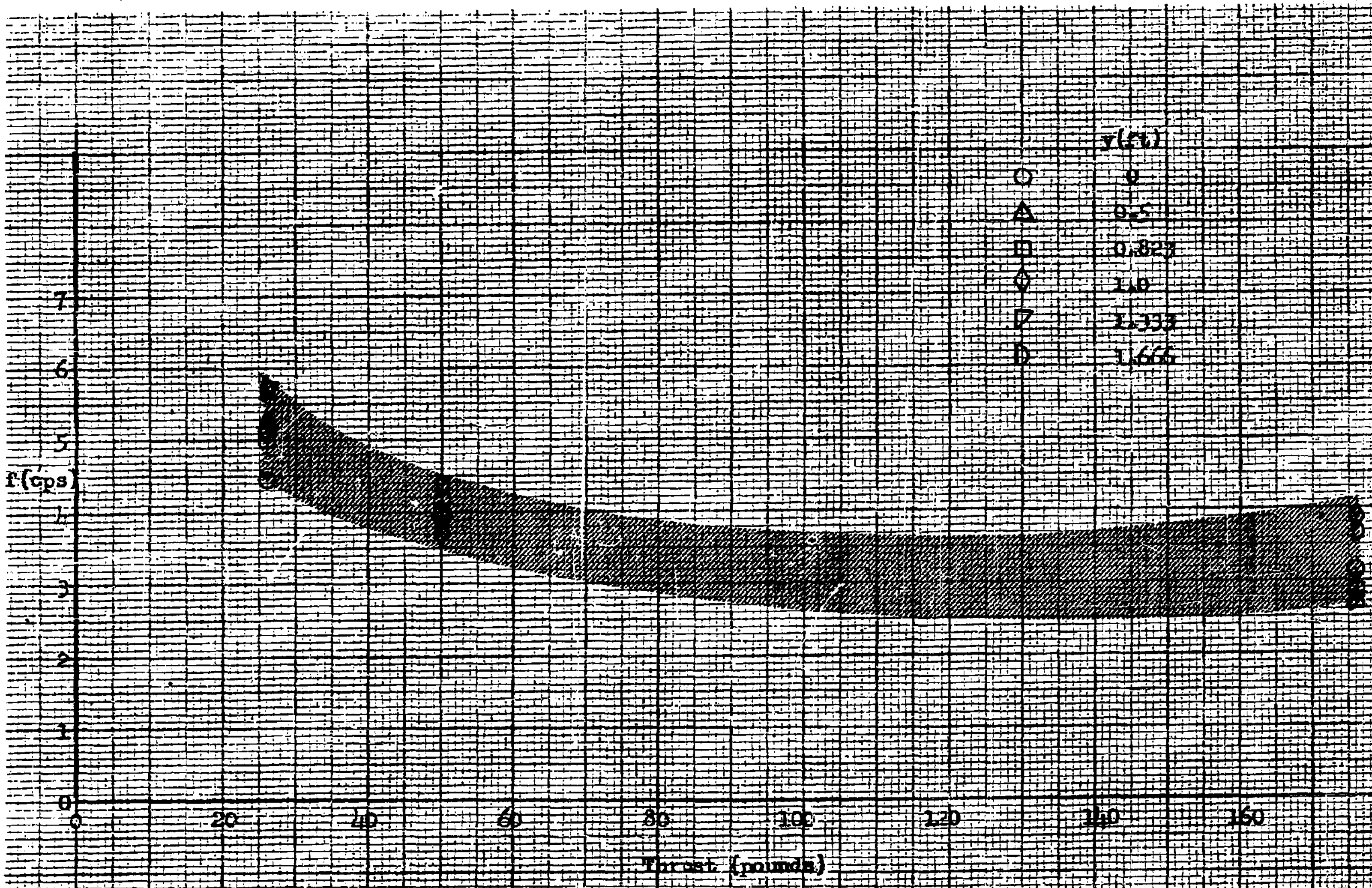


Figure 30 Wave Frequency, Plenum Chamber

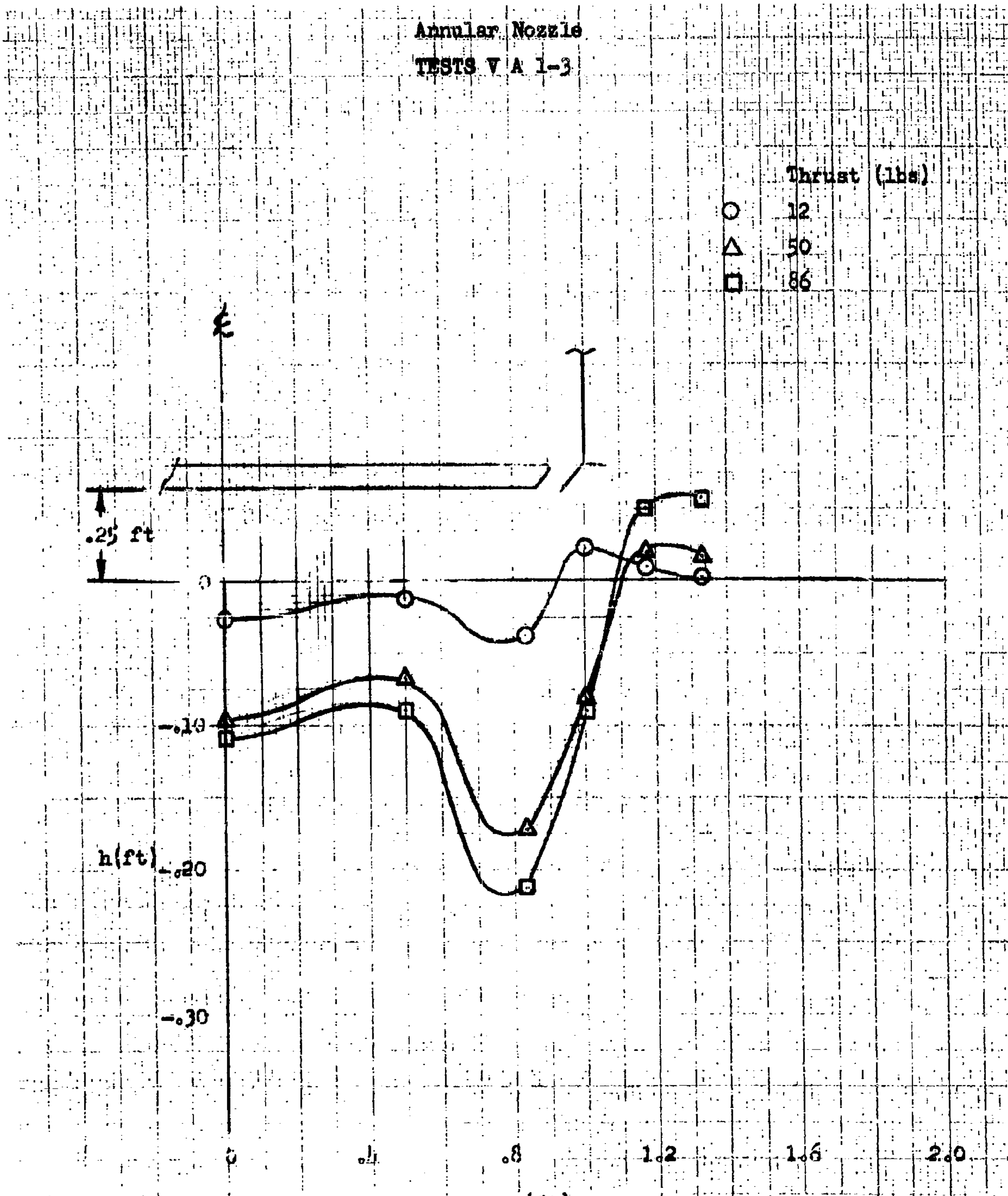


Figure 81 Water Surface Displacement

S-128

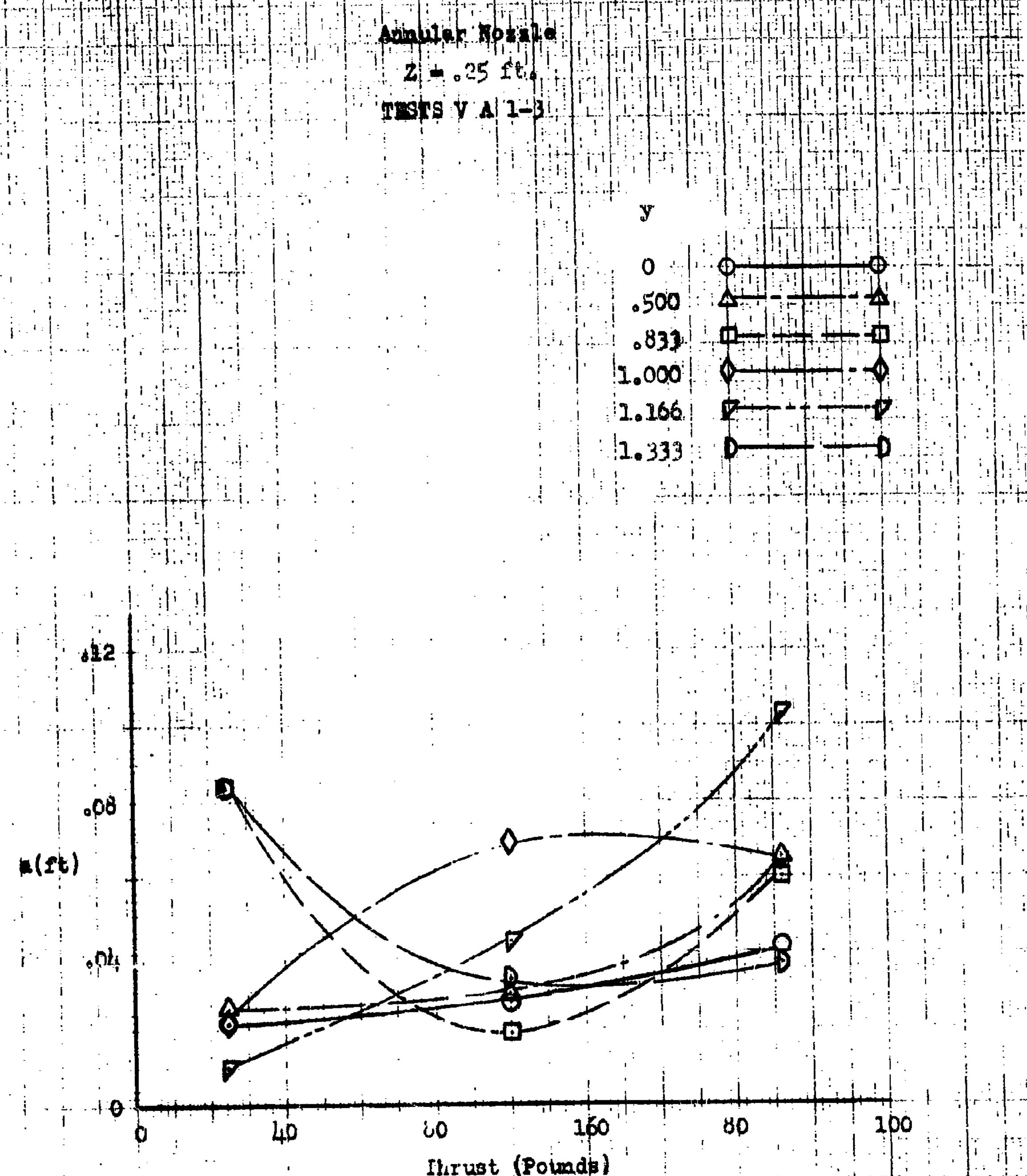


Figure 82 Wave Amplitude

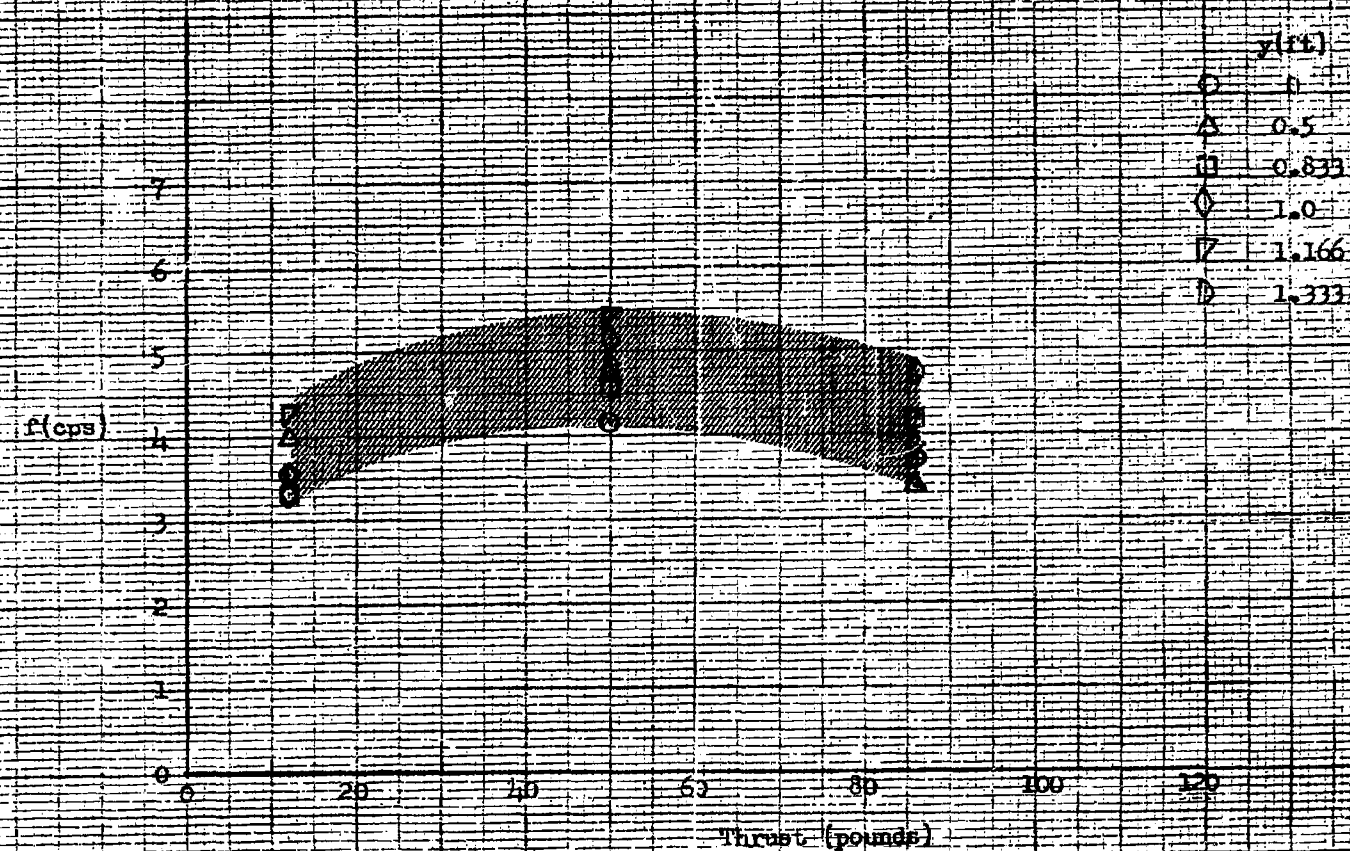


Figure 83 Wave Frequency, Annular Nozzle

APPENDIX I

DESCRIPTION OF SOILS AND TEST SITES

Introduction

1. The duct adapter test program was conducted at the U. S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi during the period of 23 August to 23 September 1960. The Waterways Experiment Station supported the tests by furnishing the sites, performing necessary soils classifications, and determining the soil condition at the time of the tests. Presented here is a description of the test sites, classification of materials tested, and condition of materials at time of testing.

Terminology

2. Pertinent terms used in this report are defined as follows:

   a. Unified Soil Classification System. The Unified Soil Classification System, which has been adopted as standard by the Corps of Engineers and the Bureau of Reclamation and is in general use by several other agencies, is used as a basis for classification of the soils tested. This system is based on the identification of soils according to their textural and plastic qualities and on their grouping with respect to behavior. The soil is given a descriptive name and a letter symbol indicating its principal characteristics. The following properties are used as a basis for classification:

      (1) Percentage of gravel, sand, and fines (fraction passing No. 200 sieve).

      (2) Shape of grain-size distribution curve.

      (3) Plasticity and compressibility characteristics.

      A complete description of the Unified Soil Classification System is given in Waterways Experiment Station Technical Memorandum No. 3-357 dated March 1953.

   b. Atterberg limits. The Atterberg limits are defined briefly as the water content of a soil at the transition points between the general stages of consistency; that is, liquid,

2. b. plastic, semisolid, and solid stages. The liquid limit (LL) and the plastic limit (PL) express the upper and lower limits, respectively, of the plastic range of a soil. The difference between these two limits expresses numerically the plasticity of a soil and is referred to as the plasticity index (PI). The test procedures used for determining the liquid and plastic limits were essentially the same as ASTM Designations D 423-39 and D 424-39, respectively.

c. Gradation. Soil gradation refers to the distribution of grain sizes in soils. This distribution is normally shown by a grain-size curve in which grain size in millimeters is plotted against percentage of fines by weight. Sieve analysis tests (ASTM C 136-46) were used for determining the grain-size distribution of soil particles coarser than a 200-mesh sieve (0.074 millimeters), and a hydrometer analysis (ASTM D 422-54T) was used for determining grain-size distribution for materials finer than a 200-mesh sieve.

d. Water Content. Water content (w) is the ratio, expressed as a percentage, of the weight of water in a soil mass to the weight of the solid matter. Tests were conducted in accordance with ASTM D 698-58T.

e. Density. Density of a soil is the weight per unit volume; in this report it is expressed as dry density in pounds per cubic foot. Tests were conducted by the sand-density and drive-cylinder methods in accordance with Corps of Engineers' procedures.

Description of Soils and Test Sites

3. Tests were performed on the following soils and test sites:

a. Lean clay (CL)
b. Sand (SP)
   (1) Dry
c. Sandy gravel (GW)
d. Water

4. Grain-size distribution curves and Atterberg limits data for the soils tested are shown on plate 1. A narrative description of the soils and condition of test sites is presented in the following paragraphs.

5. <u>Lean Clay</u>. The material used was a fine-grained soil of medium plasticity (PI of 13) which classified as a lean clay (CL). This soil is commonly referred to as a loess deposit and is typical of loess formations found throughout the midwestern part of the United States and many other areas of the world such as the southern edge of the Gobi Desert in central Asia, the Yellow Earth Area in northwestern China, central Europe, Palestine, and the western half of the Union of South Africa. Tests were conducted on the loess soil under the following conditions:

a. <u>Plowed Section (Flat)</u>. Tests 42 through 45 and 47 through 55 were conducted in a flat plowed section approximately 20 by 250 feet in area. The material was scarified by one pass of the scarifying teeth on a motor patrol and then pulverized to a depth of about 9 inches with two passes of a pulvimixer. This resulted in a very loose material simulating a freshly plowed flat field which might be used for sowing grain crops such as wheat, oats, etcetera. The area contained material ranging in size from 3-inch clods of soil to dust. The dry density ranged from 56 to 73 pounds per cubic foot, and the water content ranged from 9 to 22 percent. Actual test values of water content and density are given in table 1.

6. <u>Sand</u>. The sand used in the tests classified as a non-plastic, uniform, fine sand (SP) and was obtained from a sand bar along a small river in the Vicksburg area. This sand is typical of many river bar sands found throughout the world, and the behavior under blast would be about the same for any sand of similar gradation, density, and water content. Tests were conducted on sand sections constructed under shelter for the following conditions:

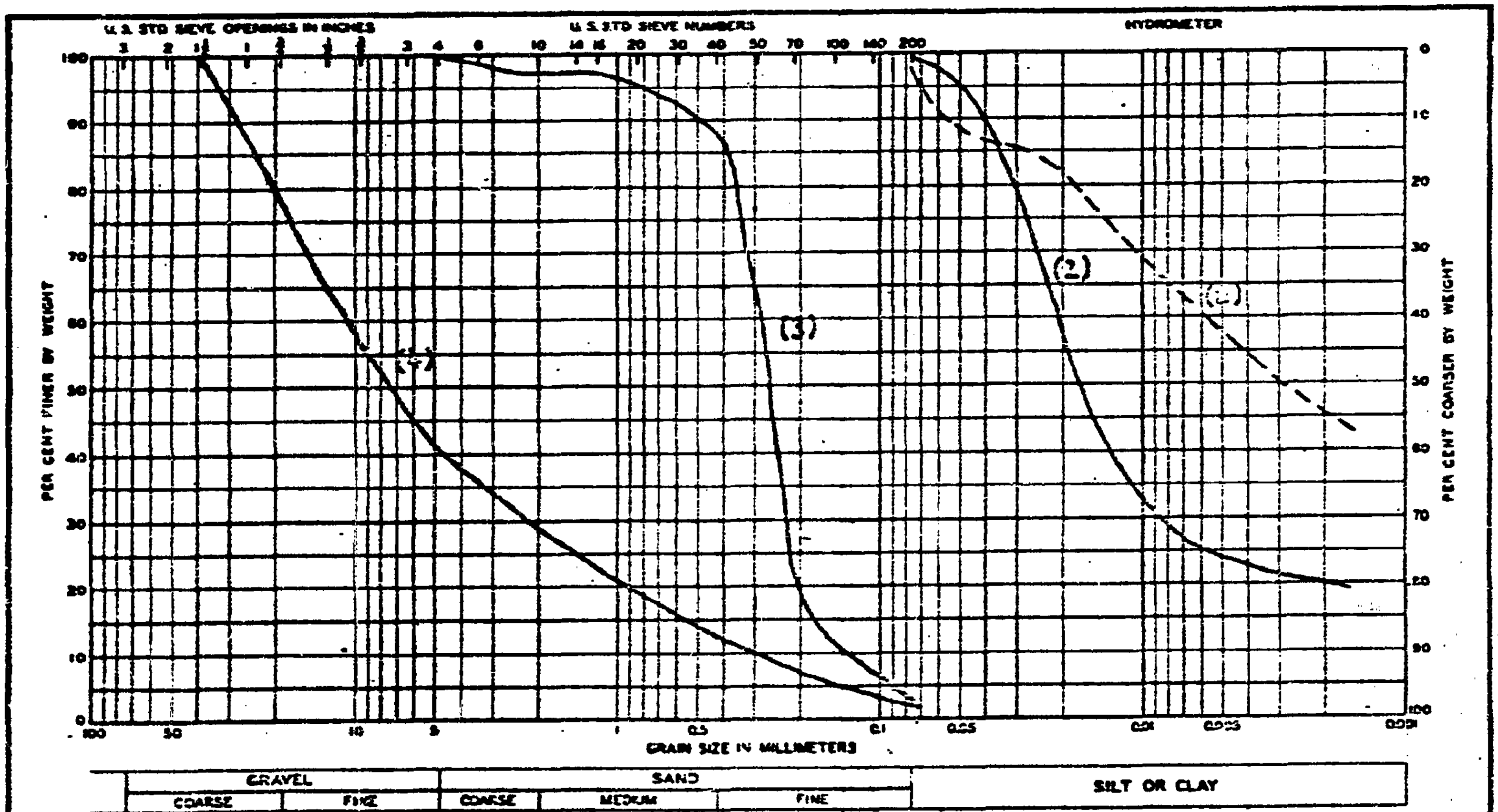
a. <u>Dry Sand</u>. Tests 26 through 41, 46, and 56 through 59 were conducted on test sections which were 20 feet wide, 50 feet long, and 1 foot deep and were constructed of air-dry sand. The material was placed in a trench section and was hand-spread to grade. Water content values varied from about .2 percent at the surface to .9 percent at the bottom of the layer. The sand was in a relatively loose state and had an average dry density of about 91 pounds per cubic foot.

7. <u>Sandy Gravel</u>. The material used in these tests was non-plastic, well graded sandy gravel (GW) with $1\frac{1}{2}$ inch maximum size particles. The material was obtained from an alluvial gravel bar deposit which is typical of such deposits along many streams throughout the world.

7. (continued)

The sandy gravel was placed in a trench section 20 feet wide, 60 feet long, and one foot deep. This material had been sprinkled and compacted prior to some tests conducted in June 1960. The eroded sections left by those tests were repaired with no additional compaction or moisture being added. The average dry density of the material was 118 pounds per cubic foot and the water content varied from 3.2 to 4.3 percent.

8. Water. Tests 1 through 25 were performed over water which was 22 inches deep and was confined by sand dikes to a pool approximately 40 feet wide by 100 feet long. The dikes were sloped to approximately 1 on 3 to dissipate any wave action occurring during the tests. Data for developing a profile of the trough produced under the various tests were obtained by instrumenting the area under the ducted fan adapters with a series of wave rods and recording the water elevation on an oscillograph.



NUMBER	DEPTH	NATURAL MOISTURE	L.L.	P.L.	P.I.	CLASSIFICATION
(1)			38	25	13	Lean clay (CL)
(2)			70	23	47	Fat clay (CH)
(3)			Nonplastic			Uniform fine sand (SP)
(4)			Nonplastic			Sandy gravel (GW)

CLASSIFICATION DATA FOR SOILS USED IN DOWNWASH IMPINGEMENT STUDY

Plate 1

APPENDIX I, TABLE I

SUMMARY OF SOIL TESTS FOR DOWNWASH IMPINGEMENT STUDY

Test No.	Soil Type and Condition	Soil Conditions Depth In.	Moisture Content, %		Dry Density lb/cu ft
1-25	Water	--	--		--
26-28	Sand	0-2	0.2)		
		2-4	0.2)		
		4-6	0.3)		
		6-8	0.3)	--	91.5
		8-10	0.9)		
		10-12	0.8)		
29-41	Sand	0-3	0.2)		
		3-5	0.3)		
		5-8	0.4)	--	90.5
		8-10	0.3)		
		10-12	0.3)		
42	Lean clay (plowed)	0-10	20.6		57.8
	Lean clay (below depth of plowing)	10-14	24.7		87.1
43 & 44	Lean clay (plowed)	0-3	18.5)		
		3-6	21.0)		
		6-8	21.3)	--	58.2
		8-10	20.7)		
45	Lean clay (plowed)	5-8	19.8		59.1
46	Sand	0-6	0.3		--
		6-12	0.7		--
47	Lean clay (plowed)	0-3	9.6)		
		3-5	19.0)		
		5-8	19.4)	--	57.6
		8-10	20.2)		
48	Lean clay (plowed)	2-4	15.6)		
		5-8	19.7)	--	62.1

Test No.	Soil Type and Condition	Soil Conditions Depth In.	Moisture Content, %	Dry Density lb/cu ft
49	Lean clay (plowed)	0-3	13.8	64.0
	Lean clay (below depth of plowing)	9-12	20.3	93.4
50	Lean clay (below depth of plowing)	9-12	21.3	94.9
51	Lean clay (plowed)	0-3	14.7	61.0
52	Lean clay (plowed)	0-3	18.2	63.1
53	Lean clay (plowed)	6-9	19.9	71.2
54	Lean clay (plowed)	0-5	13.9	68.7
55	Lean clay (plowed)	0-10	17.1	72.2
56-59	Sand	0-6	0.4	--
		6-12	0.5	--
60-68	Sandy gravel	0-3 3-5 5-7 7-9 9-11	0.3) 0.7) 2.1) -- 2.5) 3.8)	118.2

APPENDIX II

TEST CONDITIONS

Soil Designation	Z or Z/D	w	Test Time	Adapter	Remarks
I B 42	3.0	150	1 min.	Side by Side	Wind 2-4 mph
I B 43	3.0	60	1 min.	Side by Side	
I B 44	3.0	15	1 min.	Side by Side	
I B 45	3.0	30	1 min.	Side by Side	Wind 0-2 mph
I B 47	.5	15	1 min.	Side by Side	Wind 0-2 mph
I B 48	.5	30	1 min.	Side by Side	Wind 0-4 mph
I B 49	.5	60	1 min.	Side by Side	Wind 0-4 mph
I B 50	.5	150	1 min.	Side by Side	Wind 0-2 mph
I B 51	.25 ft.	8.40 to 31.25	1 min.	Plenum Chamber	Trial run with variable disk loading for observation only
I B 52	.25 ft.	8.40	1 min.	Plenum Chamber	Wind 0-4 mph
I B 53	.25 ft.	31.25	1 min.	Plenum Chamber	Wind 0-4 mph
I B 54	.25 ft.	9.64	1 min.	Annular Nozzle	
I B 55	.25 ft.	16.6	1 min.	Annular Nozzle	Wind 0-2 mph
III A 26	.5	150	1 min.	Side by Side	Wind 10-15 mph
III A 27	.5	100	1 min.	Side by Side	Wind 5-12 mph
III A 28	.5	60	1 min.	Side by Side	Wind 10-16 mph
III A 29	.5	30	1 min.	Side by Side	Wind 10-15 mph
III A 30	.5	15	1 min.	Side by Side	Wind 10-15 mph
III A 31	1.5	15	1 min.	Side by Side	Wind 5-8 mph, hole profile measured
III A 32	1.5	30	1 min.	Side by Side	Wind 3-4 mph, hole profile measured
III A 33	1.5	60	50 sec.	Side by Side	Wind 3-4 mph, hole profile measured
III A 34	1.5	100	30 sec.	Side by Side	Wind 2-4 mph
III A 35	1.5	150	18 sec.	Side by Side	Wind 2-4 mph
III A 36	3.0	15	1 min.	Side by Side	Wind 6-9 mph
III A 37	3.0	30	1 min.	Side by Side	
III A 38	3.0	60	1 min.	Side by Side	Wind 0-9 mph
III A 39	3.0	100	45 sec.	Side by Side	Wind 6-9 mph
III A 40	3.0	150	40 sec.	Side by Side	Wind 3-5 mph

Soil Designation	Z or Z/D	w	Test Time	Adapter	Remarks
III A 41	1.5	60	50 sec.	Side by Side	Wind 3-4 mph Extended ducts, hole profile measured
III A 46	1.5	60	50 sec.	Side by Side	Wind 0-2 mph, Single duct impingement, hole profile obtained
III A 56	.25 ft.	9.64	1 min.	Annular Nozzle	Wind 0-2 mph
III A 57	.25 ft.	16.6	1 min.	Annular Nozzle	Wind 0-2 mph
III A 58	.25 ft.	8.40	1 min.	Plenum Chamber	Wind 0-2 mph
III A 59	.25 ft.	31.25	1 min.	Plenum Chamber	
IV A 60	.25 ft.	8.40	1 min.	Plenum Chamber	Wind 0-2 mph
IV A 61	.25 ft.	31.25	1 min.	Plenum Chamber	Wind 0-2 mph
IV A 62	.25 ft.	9.64	1 min.	Annular Nozzle	Wind 2-4 mph
IV A 63	.25 ft.	16.6	1 min.	Annular Nozzle	Wind 0-2 mph
IV A 64	.5	15	1 min.	Side by Side	Wind 2-4 mph
IV A 65	.5	60	1 min.	Side by Side	Wind 2-4 mph
IV A 66	.5	150	10 sec.	Side by Side	Wind 0-2 mph
IV A 67	3.0	60	1 min.	Side by Side	Wind 0-2 mph
IV A 68	3.0	150	23 sec.	Side by Side	Wind 0-2 mph
V A 1	.25 ft.	16.60	-	Annular Nozzle	
V A 2	.25 ft.	9.64	-	Annular Nozzle	
V A 3	.25 ft.	2.31	-	Annular Nozzle	
V A 4	.25 ft.	31.25	-	Plenum Chamber	No wave rod readings obtained
V A 5		31.25	-	Plenum Chamber	
V A 6	.25 ft.	8.40	-	Plenum Chamber	
V A 7	.25 ft.	4.36	-	Plenum Chamber	
V A 8	3.0	8	-	Side by Side	
V A 9	3.0	15	-	Side by Side	
V A 10	3.0	30	-	Side by Side	
V A 11	3.0	60	-	Side by Side	
V A 12	3.0	100	-	Side by Side	

Soil Designation	Z or Z/D	W	Test Time	Adapter	Remarks
V A 13	3.0	150	-	Side by Side	
V A 14	1.5	8	-	Side by Side	
V A 15	1.5	15	-	Side by Side	
V A 16	1.5	30	-	Side by Side	
V A 17	1.5	60	-	Side by Side	
V A 18	1.5	100	-	Side by Side	
V A 19	1.5	150	-	Side by Side	
V A 20	.5	8	-	Side by Side	
V A 21	.5	15	-	Side by Side	
V A 22	.5	30	-	Side by Side	
V A 23	.5	60	-	Side by Side	
V A 24	.5	100	-	Side by Side	
V A 25	.5	150	-	Side by Side	